A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater, Estuarine, and Marine Ecosystems

Volume II – Design and Implementation of Sediment Quality Investigations

Submitted to:

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British Columbia Ministry of Environment, Lands, and Parks
Industrial Wastes and Hazardous Contaminants Branch
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Victoria, British Columbia
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Submitted – May 2002 – by:

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Executive Summary

Traditionally, concerns relative to the management of aquatic resources in freshwater ecosystems have focused primarily on water quality. As such, early aquatic resource management efforts were often directed at assuring the potability of surface water or groundwater sources. Subsequently, the scope of these management initiatives expanded to include protection of instream (i.e., fish and aquatic life), agricultural, industrial, and recreational water uses. While initiatives undertaken in the past twenty years have unquestionably improved water quality conditions, a growing body of evidence indicates that management efforts directed solely at the attainment of surface water quality may not provide an adequate basis for protecting the designated uses of aquatic ecosystems.

In recent years, concerns relative to the health and vitality of aquatic ecosystems have begun to reemerge in North America. One of the principal reasons for this is that many toxic and bioaccumulative chemicals [such as metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorophenols, organochlorine pesticides (OC pesticides), and polybrominated diphenyl ethers]; which are found in only trace amounts in water, can accumulate to elevated levels in sediments. Some of these pollutants, such as OC pesticides and PCBs, were released into the environment long ago. The use of many of these substances has been banned in North America for more than 30 years; nevertheless, these chemicals continue to persist in the environment. Other contaminants enter our waters every day from industrial and municipal discharges, urban and agricultural runoff, and atmospheric deposition from remote sources. Due to their physical and chemical properties, many of these substances tend to accumulate in sediments. In addition to providing sinks for many chemicals, sediments can also serve as potential sources of pollutants to the water column when conditions change in the receiving water system (e.g., during periods of anoxia, after severe storms).

Information from a variety of sources indicates that sediments throughout North America are contaminated by a wide range of toxic and bioaccumulative substances, including metals, PAHs, PCBs, OC pesticides, a variety of semi-volatile organic chemicals (SVOCs), and polychlorinated dibenzo-*p*-dioxins and furans (PCDDs and PCDFs). For example, contaminated sediments pose a major risk to the beneficial uses of aquatic ecosystems throughout the Great Lakes basin, including 43 areas of concern (AOCs) that have been identified by the International Joint Commission. The imposition of fish consumption advisories has adversely affected commercial, sport, and food fisheries in many areas. In addition, degradation of the benthic community and other factors have adversely affected fish and wildlife populations. Furthermore, fish in many of these areas have been observed to have higher levels of tumors and other abnormalities than fish from reference areas. Contaminated sediments have also threatened the viability of many commercial ports through the imposition of restrictions on dredging of navigational channels and disposal of dredged materials. Overall, contaminated sediments have been linked to 11 of the 14 beneficial use impairments that have been documented at the Great Lakes AOCs. Such use impairments have also been observed elsewhere in Canada and the United States.

In response to the concerns that have been raised regarding contaminated sediments, responsible authorities throughout North America have launched programs to support the assessment, management, and remediation of contaminated sediments. The information generated under these programs provide important guidance for designing and implementing investigations at sites with contaminated sediments. In addition, guidance has been developed under various sediment-related programs to support the collection and interpretation of sediment quality data. While such guidance has unquestionably advanced the field of sediment quality assessments, the users of the individual guidance documents have expressed a need to consolidate this information into an integrated ecosystem-based framework for assessing and managing sediment quality in freshwater ecosystems (i.e., as specified under the Great Lakes Water Quality Agreement). Practitioners in this field have also indicated the need for additional guidance on the applications of the various tools that support sediment quality assessments. Furthermore, the need for additional guidance on the design of sediment quality monitoring programs and on the interpretation of the resultant data has been identified.

This guidance manual, which comprises a three-volume series, is not intended to supplant the existing guidance on sediment quality assessment. Rather, this guidance manual is intended to further support the design and implementation of assessments of sediment quality conditions by:

- Presenting an ecosystem-based framework for assessing and managing contaminated sediments (Volume I);
- Describing the recommended procedures for designing and implementing sediment quality investigations (Volume II); and,
- Describing the recommended procedures for interpreting the results of sediment quality investigations (Volume III).

The first volume of the guidance manual, ***An Ecosystem-Based Framework for Assessing and Managing Contaminated Sediments in the Freshwater Ecosystems***, describes the five step process that is recommended to support the assessment and management of sediment quality conditions (i.e., relative to sediment-dwelling organisms, aquatic-dependent wildlife, and human health). Importantly, the document provides an overview of the framework for ecosystem-based sediment quality assessment and management (Chapter 2). In addition, the recommended procedures for identifying sediment quality issues and concerns and compiling the existing knowledge base are described (Chapter 3). Furthermore, the recommended procedures for establishing ecosystem goals, ecosystem health objectives, and sediment management objectives are presented (Chapter 4). Finally, methods for selecting ecosystem health indicators, metrics, and targets for assessing contaminated sediments are described (Chapter 5). Together, this guidance is intended to support planning activities related to contaminated sediment assessments, such that the resultant data are likely to support sediment management decisions at the site under investigation. More detailed information on these and other topics related to the assessment and management of contaminated sediments can be found in the publications listed in the bibliography (Appendix 2).

The second volume of the series, ***Design and Implementation of Sediment Quality Investigations***, describes the recommended procedures for designing and implementing sediment quality assessment programs. More specifically, Volume II provides an overview of the recommended framework for assessing and managing sediment quality conditions (Chapter 2). In addition this volume describes the recommended procedures for conducting preliminary and detailed site investigations to assess sediment quality conditions (Chapters 3 and 4). Furthermore, the factors that need to be considered in the development of sampling and analysis plans for assessing contaminated sediments are described (Chapter 5). Supplemental guidance on the design of sediment sampling programs, on the evaluation of sediment quality data, and on the management of contaminated sediment is provided in the Appendices to Volume II. The types and objectives of sediment quality assessments that are commonly conducted in freshwater ecosystems are also described in the Appendices of this volume.

The third volume in the series, ***Interpretation of the Results of Sediment Quality Investigations***, describes the four types of information that are commonly used to assess contaminated sediments, including sediment and pore water chemistry data (Chapter 2), sediment toxicity data (Chapter 3), benthic invertebrate community structure data (Chapter 4), and bioaccumulation data (Chapter 5). Some of the other tools that can be used to support assessments of sediment quality conditions are also briefly described (e.g., fish health assessments; Chapter 6). The information compiled on each of the tools includes:

descriptions of its applications, advantages, and limitations; discussions on the availability of standard methods, the evaluation of data quality, methodological uncertainty, and the interpretation of associated data; and, recommendations to guide the use of each of these individual indicators of sediment quality conditions. Furthermore, guidance is provided on the interpretation of data on multiple indicators of sediment quality conditions (Chapter 7). Together, the information provided in the three-volume series is intended to further support the design and implementation of focused sediment quality assessment programs.

List of Acronyms

%	percent
µg	microgram
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
µmol/g	micromoles per gram
AET	apparent effects threshold
AETA	Apparent Effects Threshold Approach
Al	aluminum
ANOVA	analysis of variance
AOC	Area of Concern
APHA	American Public Health Association
ARCS Program	Assessment and Remediation of Contaminated Sediments Program
ASTM	American Society for Testing and Materials
AVS	acid volatile sulfides
BCE	British Columbia Environment
BCWMA	British Columbia Waste Management Act
BEST	biomonitoring of environmental status and trends
BSAF	biota-sediment bioaccumulation factor
CA	Consensus Approach
CAC	citizens advisory committee
CCME	Canadian Council of Ministers of the Environment
CCREM	Canadian Council of Resource and Environment Ministers
CDF	confined disposal facility
CEPA	Canadian Environmental Protection Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CI	confidence interval
CLP	Contract Laboratory Program
COC	contaminant of concern
COPC	chemical of potential concern
CRLD	contract required detection limit
CSO	combined sewer overflow
CSR	Contaminated Sites Regulation
CWA	Clean Water Act
-d	- days
DDT	dichlorodiphenyl-trichloroethane
DDTs	*p,p'*-DDT, *o,p'*-DDT, *p,p'*-DDE, *o,p'*-DDE, *p,p'*-DDD, *o,p'*-DDD, and any metabolite or degradation product
DELT	deformities, fin erosion, lesions, and tumors
DL	detection limit

DM	dredged material
DO	dissolved oxygen
DOE	Department of the Environment
DOI	Department of the Interior
DQO	data quality objective
DSI	detailed site investigation
DW	dry weight
EC	Environment Canada
EC_{50}	median effective concentration affecting 50 percent of the test organisms
EEC	European Economic Community
ELA	Effects Level Approach
EMAP	Environmental Monitoring and Assessment Program
EPT	Ephemeroptera, Plecoptera, Trichoptera (i.e., mayflies, stoneflies, caddisflies)
EqPA	Equilibrium Partitioning Approach
ERL	effects range low
ERM	effects range median
EROD	ethoxyresorufin-*O*-deethylase
ESG	equilibrium-partitioning sediment quality guidelines
FCV	final chronic values
FD	factual determinations
FIFRA	Federal Insecticide, Rodenticide and Fungicide Act
gamma-BHC	gamma-hexachlorocyclohexane (lindane)
GFAA	graphite furnace atomic absorption
GIS	geographic information system
-h	- hours
H_2S	hydrogen sulfide
HC	Health Canada
Hcl	hydrochloric acid
IBI	Index of biotic integrity
IC_{50}	median inhibition concentration affecting 50 percent of test organisms
ICP	inductively coupled plasma-atomic emission spectrometry
ID	insufficient data
IDEM	Indiana Department of Environmental Management
IJC	International Joint Commission
IWB	index of well-being
K_{oc}	organic carbon partition coefficients
K_{ow}	octanol-water partition coefficients
Kp	sediment/water partition coefficients
LC_{50}	median lethal concentration affecting 50 percent of the test organism
LCS/LCSDs	laboratory control sample/laboratory control sample duplicates
Li	lithium
LMP	lakewide management plan
LOD	limit of detection
LOEC	lowest observed effect concentration
LRMA	Logistic Regression Modeling Approach

mean PEC-Q	mean probable effect concentration quotient
MESL	MacDonald Environmental Sciences Ltd.
MET	minimal effect threshold
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mgs	milligrams
mIBI	macroinvertebrate index of biotic integrity
-min	- minutes
mm	millimeter
mm	millimeters
MPRSA	Marine Protection, Research, and Sanctuaries Act
MS/MSDs	matrix spike/matrix spike duplicates
MSD	minimum significant difference
n	number of samples
NAWQA	National Water Quality Assessment
NEPA	National Environmental Policy Act
NG	no guideline available
NH_3	unionized ammonia
NH_4^+	ionized ammonia
NOAA	National Oceanic and Atmospheric Administration
NOEC	no observed effect concentration
NPDES	National Pollutant Discharge and Elimination System
NPL	National Priorities List
NPO	nonpolar organics
NR	not reported
NRDA	natural resource damage assessment
NSQS	National Sediment Quality Survey
NSTP	National Status and Trends Program
NT	not toxic
NYSDEC	New York State Department of Environmental Conservation
OC	organic carbon
OC pesticides	organochlorine pesticides
OECD	Organization of Economic Cooperation and Development
OEPA	Ohio Environmental Protection Agency
OERR	Office of Emergency and Remedial Response
OPA	Oil Pollution Act
OPTTS	Office of Prevention, Pesticides, and Toxic Substances
OSW	Office of Solid Waste
OW	The Office of Water
PAET	probable apparent effects threshold
PAHs	polycyclic aromatic hydrocarbons
PARCC	precision, accuracy, representativeness, completeness, and comparability
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-*p*-dioxins
PCDFs	polychlorinated dibenzofurans
PCS	permit compliance system

PEC	probable effect concentration (consensus-based)
PEC-Q	probable effect concentration quotient
PEL	probable effect level
PEL-HA28	probable effect level for *Hyalella azteca*; 28-day test
PQL	protection quantification limit
PSDDA	Puget Sound Dredged Disposal Analysis
PSEP	Puget Sound Estuary Program
PSI	preliminary site investigation
QA/QC	quality assurance/quality control
QAPP	quality assurance project plan
QHEI	qualitative habitat evaluation index
RAP	remedial action plan
RCRA	Resource Conservation and Recovery Act
REF	reference sediment
RPD	relative percent difference
RRH	rapidly rendered harmless
RSD	relative standard deviation
SAB	Science Advisory Board
SAG	Science Advisory Group
SAP	sampling and analysis plan
SEC	sediment effect concentration
SEL	severe effect level
SEM	simultaneously extracted metals
SEM - AVS	simultaneously extracted metal minus acid volatile sulfides
SETAC	Society of Environmental Toxicology and Chemistry
SLCA	Screening Level Concentration Approach
SMS	sediment management standards
SOD	sediment oxygen demand
SPMD	semipermeable membrane device
SQAL	sediment quality advisory levels
SQC	sediment quality criteria
SQG	sediment quality guideline
SQRO	sediment quality remediation objectives
SQS	sediment quality standard
SSLC	species screening level concentration
SSZ	sediment sampling zone
STP	sewage treatment plant
SVOC	semivolatile organic compound
SVOC	semi-volatile organic chemical
T	toxic
TEC	threshold effect concentration
TEL	threshold effect level
TEL-HA28	threshold effect level for *Hyalella azteca*; 28 day test
TET	toxic effect threshold
TIE	toxicity identification evaluation
TMDL	total maximum daily load

TOC	total organic carbon
tPAH	total polycyclic aromatic hydrocarbons
TRA	Tissue Residue Approach
TRG	tissue residue guideline
TRV	toxicity reference values
TSCA	Toxic Substances Control Act
USACE	United States Army Corps of Engineers
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VOC	volatile organic compound
WDOE	Washington Department of Ecology
WMA	Waste Management Act
WQC	water quality criteria
WQS	water quality standards
WW	wet weight

Glossary of Terms

Acute toxicity – The response of an organism to short-term exposure to a chemical substance. Lethality is the response that is most commonly measured in acute toxicity tests.

Acute toxicity threshold – The concentration of a substance above which adverse effects are likely to be observed in short-term toxicity tests.

Altered benthic invertebrate community – An assemblage of benthic invertebrates that has characteristics (i.e., mIBI score, abundance of EPT taxa) that are outside the normal range that has been observed at uncontaminated reference sites.

Aquatic ecosystem – All the living and nonliving material interacting within an aquatic system (e.g., pond, lake, river, ocean).

Aquatic invertebrates – Animals without backbones that utilize habitats in freshwater, estuaries, or marine systems.

Aquatic organisms – The species that utilize habitats within aquatic ecosystems (e.g., aquatic plants, invertebrates, fish, amphibians and reptiles).

Benthic invertebrate community – The assemblage of various species of sediment-dwelling organisms that are found within an aquatic ecosystem.

Bioaccumulation – The net accumulation of a substance by an organism as a result of uptake from all environmental sources.

Bioaccumulation-based sediment quality guidelines (SQGs) – Sediment quality guidelines that are established to protect fish, aquatic-dependent wildlife, and human health against effects that are associated with the bioaccumulation of contaminants in sediment-dwelling organisms and subsequent food web transfer.

Bioaccumulative substances – The chemicals that tend to accumulate in the tissues of aquatic and terrestrial organisms.

Bioavailability – Degree to which a chemical can be absorbed by and/or interact with an organism.

Bioconcentration – The accumulation of a chemical in the tissues of an organism as a result of direct exposure to the surrounding medium (e.g., water; i.e., it does not include food web transfer).

Biomagnification – The accumulation of a chemical in the tissues of an organism as a result of food web transfer.

Chemical benchmark – Guidelines for water or sediment quality which define the concentration of contaminants that are associated with low or high probabilities of observing harmful biological effects, depending on the narrative intent.

Chemical of potential concern – A substance that has the potential to adversely affect surface water or biological resources.

Chronic toxicity – The response of an organism to long-term exposure to a chemical substance. Among others, the responses that are often measured in chronic toxicity tests include lethality, decreased growth, and impaired reproduction.

Chronic toxicity threshold – The concentration of a substance above which adverse effects are likely to be observed in long-term toxicity tests.

Congener – A member of a group of chemicals with similar chemical structures (e.g., PCDDs generally refers to a group of 75 congeners that consist of two benzene rings connected to each other by two oxygen bridges).

Consensus-based probable effect concentrations (PECs) – The PECs that were developed from published sediment quality guidelines and identify contaminant concentrations above which adverse biological effects are likely to occur.

Consensus-based threshold effect concentrations (TECs) – The TECs that were developed from published sediment quality guidelines and identify contaminant concentrations below which adverse biological effects are unlikely to occur.

Contaminants of concern (COC) – The substances that occur in environmental media at levels that pose a risk to ecological receptors or human health.

Contaminated sediment – Sediment that contains chemical substances at concentrations that could potentially harm sediment-dwelling organisms, wildlife, or human health.

Conventional variables – A number of variables that are commonly measured in water and/or sediment quality assessments, including water hardness, conductivity, total organic carbon (TOC), sediment oxygen demand (SOD), unionized ammonia (NH_3), temperature, dissolved oxygen (DO), pH, alkalinity

Core sampler – A device that is used to collect both surficial and sub-surface sediment samples by driving a hollow corer into the sediments.

Degradation – A breakdown of a molecule into smaller molecules or atoms.

DELT abnormalities – A number of variables that are measured to assess fish health, including deformities, fin erosion, lesions, and tumors.

Diagenesis – The sum of the physical and chemical changes that take place in sediments after its initial deposition (before they become consolidated into rocks, excluding all metamorphic changes).

Discharge – discharge of oil as defined in Section 311(a)(2) o f the Clean Water Act, and includes, but is not limited to, any spilling, leaking, pumping, pouring, emitting, emptying, or dumping of oil.

Ecosystem – All the living (e.g., plants, animals, and humans) and nonliving (rocks, sediments, soil, water, and air) material interacting within a specified location in time and space.

Ecosystem-based management – An approach that integrates the management of natural landscapes, ecological processes, physical and biological components, and human activities to maintain or enhance the integrity of an ecosystem. This approach places equal emphasis on concerns related to the environment, the economy, and the community (also called the ecosystem approach).

Ecosystem goals – Are broad management goals which describe the long-term vision that has been established for the ecosystem.

Ecosystem metrics – Identify quantifiable attributes of the indicators and defines acceptable ranges, or targets, for these variables.

Ecosystem objectives – Are developed for the various components of the ecosystem to clarify the scope and intent of the ecosystem goals. These objectives should include target schedules for being achieved.

Endpoint – A measured response of a receptor to a stressor. An endpoint can be measured in a toxicity test or in a field survey.

Epibenthic organisms – The organisms that live on the surface of sediments.

Exposure – Co-occurrence of or contact between a stressor (e.g., chemical substance) and an ecological component (e.g., aquatic organism).

Grab (Dredge) samplers – A device that is used to collect surficial sediments through a scooping mechanism (e.g. petite ponar dredge).

Hazardous substance – hazardous substance as defined in Section 101(14) of CERCLA.

Index of biotic integrity (IBI) – A parameter that is used to evaluate the status of fish communities. The IBI integrates information on species composition (i.e., total number of species, types of species, percent sensitive species, and percent tolerant species), on trophic composition (i.e., percent omnivores, percent insectivores, and percent pioneer species), and on fish condition.

Infaunal organisms – The organisms that live in sediments.

Injury – a measurable adverse change, either long or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a discharge of oil or release of a hazardous substance, or exposure to a product of reactions resulting from the discharge to oil or release of a hazardous substance. As used in this part, injury encompasses the phrases "injury", "destruction", and "loss". Injury definitions applicable to specific resources are provided in Section 11.62 of this part (this definition is from the Department of the Interior Natural Resource Damage Assessment Regulations).

Macroinvertebrate index of biotic integrity (mIBI) – The mIBI was used to provide information on the overall structure of benthic invertebrate communities. The scoring criteria for this metric includes such variables as number of taxa, percent dominant taxa, relative abundance of EPT taxa, and abundance of chironomids.

Mean probable effect concentration-quotient (PEC-Q) – A measure of the overall level of chemical contamination in a sediment, which is calculated by averaging the individual quotients for select chemicals of interest..

Natural resources – land, fish, wildlife, biota, air, water, ground water, drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by the federal government (including the resources of the fishery conservation zone established by the Magnuson Fishery Conservation and Management Act of 1976), State or local government, or any foreign government and Indian tribe. These natural resource have been categorized into the following five groups: surface water resources, ground water resources, air resources, geologic resources, and biological resources.

Natural resources damage assessment – the process of collecting, compiling, and analyzing information, statistics, or data through prescribed methodologies to determine damages for injuries to natural resources as set forth in this part.

Neoplastic – Refers to abnormal new growth.

Oil – oil as defined in Section 311(a)(1) of the Clean Water Act, of any kind or in any form, including, but not limited to, petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other that dredged spoil.

Piscivorus wildlife species – The wildlife species that consume fish as part of all of their diets (e.g., herons, kingfishers, otter, osprey, and mink).

Population – An aggregate of individual of a species within a specified location in time and space.

Pore water – The water that occupies the spaces between sediment particles.

Probable effect concentration (PEC) – Concentration of a chemical in sediment above which adverse biological effects are likely to occur.

Probable effect concentration-quotient (PEC-Q) – A PEC-Q is a measure of the level of chemical contamination in sediment relative to a sediment quality guideline, and is calculated by dividing the measured concentration of a substance in a sediment sample by the corresponding PEC.

Receptor – A plant or animal that may be exposed to a stressor.

Release – A release of a hazardous substance as defined in Section 101(22) of CERCLA.

Sediment – Particulate material that usually lies below water.

Sediment-associated contaminants – Contaminants that are present in sediments, including whole sediments or pore water.

Sediment chemistry data – Information on the concentrations of chemical substances in whole sediments or pore water.

Sediment-dwelling organisms – The organisms that live in, on, or near bottom sediments, including both epibenthic and infaunal species.

Sediment injury – The presence of conditions that have injured or are sufficient to injure sediment-dwelling organisms, wildlife, or human health.

Sediment quality guideline – Chemical benchmark that is intended to define the concentration of sediment-associated contaminants that is associated with a high or a low probability of observing harmful biological effects or unacceptable levels of bioaccumulation, depending on its purpose and narrative intent.

Sediment quality targets – Chemical or biological benchmarks for assessing the status of each metric.

Simultaneously extracted metals (SEM) – Divalent metals - commonly cadmium, copper, lead, mercury, nickel, and zinc - that form less soluble sulfides than does iron or manganese and are solubilized during the acidification step (0.5m HCl for 1 hour) used in the determination of acid volatile sulfides in sediments.

Stressor – Physical, chemical, or biological entities that can induce adverse effects on ecological receptors or human health.

Surface water resources – The waters of North America, including the sediments suspended in water or lying on the bank, bed, or shoreline and sediments in or transported through coastal and marine areas. This term does not include ground water or water or sediments in ponds, lakes, or reservoirs designed for waste treatment under the Resource Conservation and Recovery Act of 1976 (RCRA), 42 U.S.C. 6901-6987 or the Clean Water Act, and applicable regulations.

Threshold effect concentration (TEC) – Concentration of a chemical in sediment below which adverse biological effects are unlikely to occur.

Tissue – A group of cells, along with the associated intercellular substances, which perform the same function within a multicellular organism.

Tissue residue guideline (TRG) – Chemical benchmark that is intended to define the concentration of a substance in the tissues of fish or invertebrates that will protect fish-eating wildlife against effects that are associated with dietary exposure to hazardous substances.

Trophic level – A portion of the food web at which groups of animals have similar feeding strategies.

Trustee – Any Federal natural resources management agency designated in the National Contingency Plan and any State agency designated by the Governor of each State, pursuant to Section 107(f)(2)(B) of CERCLA, that may prosecute claims for damages under Section 107(f) or 111(b) of CERCLA; or any Indian tribe, that may commence an action under Section 126(d) of CERCLA.

Wildlife – The fish, reptiles, amphibians, birds, and mammals that are associated with aquatic ecosystems.

Whole sediment – Sediment and associated pore water.

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Chapter 1. Introduction

In response to the concerns raised regarding contaminated sediments, a number of programs have been established or expanded to support the assessment and management of contaminated sediments in the United States and Canada (Appendix 1 of Volume II). The information generated under these programs provides important guidance for designing and implementing investigations at sites with contaminated sediments (see USEPA 1994a; MacDonald 1994a; 1994b; Reynoldson *et al.* 2000; Ingersoll *et al.* 1997; USEPA and USACE 1998a; ASTM 2001a; USEPA 2000a; Krantzberg *et al.* 2001). While these guidance documents have unquestionably advanced the field of sediment quality assessment, the users of these individual guidance documents have expressed a need to consolidate this information into an integrated ecosystem-based framework for assessing and managing sediment quality in freshwater ecosystems.

This guidance manual, which comprises a three-volume series, is not intended to supplant the existing guidance documents on sediment quality assessment (e.g., USEPA 1994a; Reynoldson *et al.* 2000; USEPA and USACE 1998a; USEPA 2000a; ASTM 2001a; Krantzberg *et al.* 2001). Rather, this guidance manual is intended to further support the design and implementation of assessments of sediment quality conditions by:

- Presenting an ecosystem-based framework for assessing and managing contaminated sediments (Volume I);
- Describing the recommended procedures for designing and implementing sediment quality investigations (Volume II); and,
- Describing the recommended procedures for interpreting the results of sediment quality investigations (Volume III).

The first volume of the guidance manual, ***An Ecosystem-Based Framework for Assessing and Managing Contaminated Sediments in Freshwater Ecosystems***, describes the five step process recommended to support the assessment and management of sediment quality conditions (i.e., relative to sediment-dwelling organisms, aquatic-dependent wildlife, and human health). Importantly, the document provides an overview of the framework for ecosystem-based sediment quality assessment and management (Chapter 2). The recommended procedures for identifying sediment quality issues and concerns and compiling the existing knowledge base are described (Chapter 3). Furthermore, the recommended procedures for establishing ecosystem goals, ecosystem health objectives, and sediment management objectives are presented (Chapter 4). Finally, methods for selecting ecosystem health indicators, metrics, and targets for assessing contaminated sediments are described (Chapter 5). Together, this guidance is intended to support planning activities related to contaminated sediment assessments, such that the resultant data are likely to support sediment management decisions at the site under investigation.

The second volume of the series, ***Design and Implementation of Sediment Quality Investigations***, describes the recommended procedures for designing and implementing sediment quality assessment programs. More specifically, an overview of the recommended framework for assessing and managing sediment quality conditions process is presented in this document (Chapter 2). In addition, this volume describes the recommended procedures for conducting preliminary and detailed site investigations to assess sediment quality conditions (Chapters 3 and 4). Furthermore, the factors that need to be considered in the development of sampling and analysis plans for assessing contaminated sediments are described (Chapter 5). Supplemental guidance on the design of sediment sampling programs, on the evaluation of sediment quality data, and on the management of contaminated sediment is provided in the Appendices to this volume. The Appendices of this document also describe the types and objectives of sediment quality assessments that are commonly conducted in freshwater ecosystems.

The third volume in the series, ***Interpretation of the Results of Sediment Quality Investigations***, describes the four types of indicators that are commonly used to assess contaminated sediments, including sediment and pore water chemistry data (Chapter 2), sediment toxicity data (Chapter 3), benthic invertebrate community structure data (Chapter 4), and bioaccumulation data (Chapter 5). Some of the other indicators that can be used to support assessments of sediment quality conditions are also described (e.g., fish health assessments; Chapter 6). The information compiled on each of the indicators includes: descriptions of its applications, advantages, and limitations; discussions on the availability of standard methods, the evaluation of data quality, methodological uncertainty, and the interpretation of associated data; and, recommendations to guide its use. Furthermore, guidance is provided on the interpretation of data on multiple indicators of sediment quality conditions (Chapter 7). Together, the information provided in the three-volume series is intended to further support the design and implementation of focused sediment quality assessment programs.

Chapter 2. Recommended Framework for Assessing and Managing Sediment Quality Conditions

2.0 Introduction

Guidance on the design and implementation of sediment quality investigations is available from a number of sources (e.g., WDOE 1995; USEPA 1994a; 1998a; 1999b; 2000a; USEPA and USACE 1998a; ASTM 2001a). Based on a review of the guidance generated to date, the following framework was developed to assist in the design and implementation of efficient and effective sediment quality assessments. This framework identifies the steps that should be followed in conducting site-specific sediment quality assessment programs and comprises the following elements (Figure 2.1):

- Identifying sediment quality issues and concerns;
- Evaluating existing sediment quality data;
- Designing and implementing preliminary and detailed site assessments;
- Developing and implementing remedial action plans; and,
- Conducting confirmatory monitoring and assessment.

The recommended framework is intended to provide general guidance to support the sediment quality assessment process (Figure 2.2). More detailed guidance on preliminary and detailed site investigations is provided in Chapter 3 (Figures 2.3 and 2.4) and Chapter 4 (Figure 2.5) of Volume II, respectively.

2.1 Identify Sediment Quality Issues and Concerns

The first phase of a site-specific sediment quality assessment involves the evaluation of sediment issues and concerns at the area (or site) under investigation (see Chapter 3 of

Volume I for additional information). As a first step in this process, the pertinent historical information on the area under consideration is collected and reviewed. Information is required on the types of industries and businesses that operate or have operated in the area, on the location of wastewater treatment plants, on land use patterns in upland areas, on stormwater drainage systems, on residential developments, and on other historic, ongoing, and potential activities within the area. These data provide a basis for identifying potential sources of contaminants to aquatic ecosystems. Information on the chemical composition of wastewater effluent discharges, types of contaminants likely to be associated with non-point sources, and physical/chemical properties [e.g., octanol-water partition coefficients (K_{ow}), organic carbon partition coefficients (K_{oc}), solubility] of those substances provides a basis for developing an initial list of chemical of potential concern (COPCs) at the site. By evaluating the probable environmental fate of these COPCs, establishing a list of COPCs and locations of potential concern with respect to sediment contamination at the site is possible (Figure 2.3).

In addition to information on contaminant sources, information should be collected that helps define the ecosystem health goals and objectives (if these have not been defined; Chapter 4 of Volume I). In many jurisdictions, protection and restoration of the designated uses of the aquatic ecosystem represents a primary ecosystem health goal for areas of concern. As such, ecosystem goals in freshwater systems may be based on protection of the ecosystem as a whole, maintenance of viable populations of sportfish species, protection of human health (e.g., swimmable and fishable), or a variety of other considerations (e.g., regional stormwater management, industrial development). In turn, information on existing uses of the site provides a basis for making decisions regarding the nature and extent of the investigations that should be conducted at the site. Mudroch and McKnight (1991), Baudo and Muntau (1990) and MacDonald (1989) provide detailed descriptions of the types of background information (e.g., location and nature of industrial facilities, location and characteristics of point source effluent discharges, location of stormwater discharges, land and water uses in the vicinity of the site, and location of sediment depositional zones) that should be obtained and guidance on how these data may be used to help define sediment quality issues and concerns.

The existing data on the various indicators selected for assessing sediment quality conditions should also be collected and collated at this stage of the process. Such data may include information on sediment chemistry, tissue chemistry, sediment toxicity, benthic invertebrate and fish community structure, fish health, and the presence of fish consumption advisories (see Volume III for more information on each of these indicators). State, tribal, federal, and provincial agencies represent primary sources of such data; however, industrial interests, local governments, and environmental groups should not be overlooked.

2.2 Evaluating Existing Sediment Chemistry Information

Acquisition and evaluation of existing sediment quality data is a critical component of the sediment quality assessment process. Because such data may have been collected under a variety of programs and for a number of reasons, it is essential that these data be fully evaluated to determine their applicability in the sediment quality assessment process. This evaluation should cover the overall quality of the data set and the degree to which the data are thought to represent current conditions at the site under consideration.

Concerns regarding data quality may be resolved by evaluating the quality assurance/quality control (QA/QC) measures that were implemented during collection, transport, and analysis of sediment samples (Appendix 3 of Volume II). A number of conventions have been established to provide guidance on the field aspects of sediment sampling programs (USEPA and USACE 1998a; ASTM 2001c; USEPA 2001); this guidance can be used to evaluate the sample collection, handling, and transport procedures used in previous investigations. A diversity of standardized analytical procedures have been developed to quantify concentrations of contaminants in sediments (e.g., USEPA and USACE 1991; APHA *et al.* 1998; see Chapter 2 of Volume III). However, adherence to standard methods does not necessarily assure that project data quality objectives have been met. For this reason, evaluating the performance of analytical laboratories using the quality assurance data generated during the investigation is essential. More specifically, analytical results may be evaluated based on the reported accuracy and precision of the technique (i.e., the results of analyses performed on certified reference materials, and on split and spiked sediment samples; USEPA 1994a). Analytical detection limits are also relevant to the assessment of potential biological effects at the site. The suitability of the detection limits may be assessed by comparing them with the threshold effect concentration (TEC)-type SQGs for that substance (MacDonald *et al.* 2000). Criteria for evaluating the applicability of candidate data sets for use in sediment quality assessments are presented in Appendix 4 of Volume III.

Assessment of sediment quality conditions requires information that adequately represents the contemporary environmental conditions at the site under consideration. Therefore, the age of the data is a central question with respect to determining the applicability of the data. Natural degradative processes in the environment can lead to reductions in the concentrations of sediment-associated organic contaminants over time (Mosello and Calderoni 1990). Major events (such as storms) can result in the transport of sediments between sites, while industrial developments and/or regulatory activities can alter the sources and composition of contaminants released into the environment over time. Thus, it is important that assessments of sediment quality be undertaken with the most recent data available. In many cases, new data will need to be collected to support such assessments if the existing data is of questionable relevance (i.e., > 10 years old).

In addition to temporal variability, the sediment quality is known to vary significantly on a spatial basis (Long *et al.* 1991; 1996). Therefore, any single sample is likely to represent only a small proportion of the geographic area in which it was collected. For this reason, data from a number of stations should be available to provide a representative picture of sediment quality conditions at the site, with the actual number of stations required dependent on the size of the area under consideration, the concentrations of sediment-associated contaminants, and the variability of contaminant concentrations (see Appendix 3 of Volume II for more information for assessing the extent to which data sets represent sediment quality conditions at a site).

Another important factor to consider in evaluating the applicability of existing sediment quality data is the list of variables that were analyzed. It is important that the list of analytes reflects the existing and historical contaminant sources from land and water use activities in the area (Table 2.1). In harbors, for example, variables such as pentachlorophenol (which is often used as a preservative for pilings), tributyltin (which is often used in antifouling paints for ships), and copper (which is often used in antifouling paints for pleasure craft) should be measured. Similarly, elevated concentrations of polycyclic aromatic hydrocarbons (PAHs) and lead are frequently observed in sediments in the vicinity of urban stormwater discharges. In agricultural areas, persistent pesticides and nutrients should be considered in sediment quality assessments. At minimum, data on the levels of metals, PAHs, and polychlorinated biphenyl (PCBs) are needed to assess sediment contamination at most sites. It is also important to determine if the available biological effects data (e.g., acute toxicity tests) are relevant for determining if the management objectives established for the site are compromised by contaminated sediments (i.e., the results of chronic toxicity tests and/or benthic invertebrate community assessments are needed to determine if sediment-dwelling organisms are likely to be or have been adversely affected by sediment contamination).

Development of a project database is an important element of the overall sediment quality assessment process. Designing and populating the project database early in the process (i.e., during the collation of existing information) is beneficial to support the evaluation of current conditions and the identification of any additional investigations that may be needed at the site. In general, a relational database format is the most flexible for conducting subsequent analyses of the historic data (Field *et al.* 1999; Crane *et al.* 2000). Importantly, the format of the database should support linkage to various analytical tools, such as NOAA's Query Manager and Marplot applications and ESRI's Spatial Analyst and ArcView applications (MacDonald and Ingersoll 2000).

If the results of the data evaluation process indicate that sufficient quantities of acceptable quality data are available, then initiating the data interpretation process is possible. However, if the sediment chemistry or other historical effects data are considered to be of unacceptable quality or are not considered to adequately represent the site, additional data may be required to complete the sediment quality assessment. Such data gaps may be addressed by conducting additional sampling to acquire the data needed to support a preliminary site investigation (Section 2.3 and Chapter 3 of Volume II) and/or a detailed site investigation (Section 2.4 and Chapter 4 of Volume II).

2.3 Conducting a Preliminary Site Investigation (PSI)

The term PSI is used to describe a screening level-type investigation (e.g., Phase I and II investigations under CERCLA; Figures 2.3 and 2.4). A PSI should be conducted at any site suspected of having contaminated sediments. The PSI is intended to provide information for assessing the probability that adverse effects can be attributed to elevated concentrations of contaminants in sediments at the site. A PSI may be conducted using historical data (if deemed adequate) or by collecting additional data to fill any identified data gaps. In the PSI, evaluations of sediment quality conditions typically rely on sediment chemistry data alone (although other types of data may be used if available).

The first stage of the PSI involves the use of historical records, interviews with local individuals, reconnaissance trips, and related activities to ascertain if sediments are likely to be contaminated, to identify which locations are most likely to be affected, and to determine which substances are likely to occur in sediments at the site (Figure 2.3). If sufficient information is available and the results indicate that sediment contamination is unlikely, then no further investigations are required at the site. However, further investigation is required if insufficient information is available to evaluate the potential for sediment contamination and/or if the available information indicates that the site is likely to contain contaminated sediments (see Chapter 3 of Volume II).

The second stage of the PSI is undertaken to provide information on the general location of contaminated sediments at the site and determine the degree of any contamination that exists (Figure 2.4). This step in the PSI generally consists of three main activities, including design and implementation of a sediment sampling plan (which may utilize random and/or biased sampling designs; Chapter 5 of Volume II), chemical analysis of the samples to determine the concentrations of suspected contaminants, and comparison of the ambient contaminant concentrations to selected targets for sediment quality assessment. Numerical SQGs (such as those reported by MacDonald *et al.* 2000; USEPA 2000a) are particularly useful in this application because they provide a basis for estimating the probability of observing sediment toxicity in samples with various chemical characteristics. These activities need to be directed through the development of a sampling and analysis plan (SAP), which includes a quality assurance project plan (QAPP; see WDOE 1995 for more information on the development of a SAP; guidance on the development of a QAPP is provided in USEPA 1991a; 1991b; 1991c; 1991d; 2000b; also see Section 3.2.1 and 4.1.6 of Volume II). No further investigations are required if the results of the PSI indicate that it is unlikely that contaminants at the site are adversely affecting sediment-dwelling organisms, wildlife, or human health. However, a DSI should be conducted if the results of the PSI indicate that sediments may be contaminated by toxic and/or bioaccumulative substances at levels that are likely to adversely affect sediment-dwelling organisms, wildlife, or human health.

2.4 Conducting a Detailed Site Investigation (DSI)

A DSI should be conducted when the results of the PSI indicate that a site contains or is likely to contain concentrations of contaminants in sediments that are adversely affecting sediment-dwelling organisms, wildlife, or human health. The DSI is intended to provide detailed information on the site with contaminated sediment, including:

- The identity of contaminants that occur at hazardous levels (i.e., above the SQGs);
- The magnitude and areal extent of sediment contamination at the site; and,
- The potential and/or actual effects of sediment-associated contaminants on ecological receptors and/or human health.

By fulfilling these objectives, the DSI will provide sufficient information for assessing the risks to ecological receptors and/or human health posed by contaminated sediments and for developing a remedial action plan (RAP) for the site, if required (Figure 2.5). In many ways, the DSI is an extension of the Stage II PSI. Therefore, combining these two types of investigations under certain circumstances may be cost-effective (i.e., following the completion of a Stage I PSI, which primarily involved compilation and evaluation of existing sediment quality data and related information).

A number of important and potentially costly decisions are dependent on the results of the DSI. For this reason, it is essential that the DSI be based on a detailed study design, as articulated in the SAP and the associated QAPP. More specifically, the study should be designed to confirm or refute the presence of COPCs, to determine the spatial extent of chemical contamination (both in surficial and in deeper sediments), to identify chemical gradients (which can be used to identify possible sources of contamination), and to identify the location of sediment hot spots. While whole-sediment chemistry, sediment toxicity, and benthic invertebrate community structure are a primary focus of this investigation, the DSI should also provide data for assessing the nature, severity, and extent of contamination in pore water and biological tissues (including sediment-dwelling organisms, fish, and wildlife, as appropriate) and for assessing the status of fish communities inhabiting the area. Such information on the levels of chemical contaminants can then be evaluated relative to the SQGs, water quality criteria (WQC), or tissue residue guidelines (TRGs; Volume III).

While the results of chemical analysis of environmental samples provide important information for assessing the risks that contaminated sediments pose to human health and environmental receptors, other types of data should also be collected during the DSI to confirm the results of such assessments. Specifically, data from toxicity (including whole-sediment and pore water tests), benthic invertebrate, and fish community assessments can provide important information for assessing the effects of contaminated sediments on aquatic organisms. In addition, bioaccumulation assessments can be used to assess the potential effects of COPCs that tend to bioaccumulate in the food web and, in so doing, pose risks to aquatic-dependent wildlife and/or human health. In designing the DSI, it is important to remember that the weight of evidence required needs to be proportional to the weight of the decision that is being made. More detailed guidance on the design and implementation of DSIs is presented in Chapter 4 of Volume II, while supplemental guidance for sampling design is provided in Chapter 5 of Volume II.

2.5 Remedial Action Planning

This guidance manual is not intended to provide detailed guidance on the remedial action planning. Rather, this section of the guidance manual is included to provide an overview of the remedial action planning process to illustrate how the results of the various investigations can be applied in sediment management decisions (Figure 2.6).

The results of the DSI are intended to provide sufficient information to make a final determination as to whether the sediments at the site are contaminated to such an extent that adverse effects are occurring on aquatic life, aquatic-dependent wildlife, or human health. Remedial action may be needed at sites at which beneficial uses of the aquatic ecosystem are being adversely affected by sediment contamination. However, there are a number of planning steps that need to be completed before initiating remedial measures at a contaminated site.

One of the first steps in remediation planning involves determination of liability. Persons who are potentially responsible may include current or former owners of the contaminated site, current or former owners of nearby sites (from which the contamination could have migrated), and producers or transporters of COPCs. Some of the other steps that occur during the planning stage include assessing the need and priority for remediation, activating the site remediation process (through a voluntary remediation agreement, a remediation order, or a consent decree), developing an RAP, and obtaining approval in principle for the remediation plan.

Development of an RAP is a critical component of the contaminated site remediation process. The RAP should contain the results of any investigations conducted on the site, evaluations of various remediation options (including the results of public consultations), an evaluation of the potential impacts of the preferred remediation option, and a description of the monitoring and evaluation procedures that will be employed to assess the efficacy of the remedial measures. The reader is directed to Zarull *et al.* (2001), Krantzberg *et al.* (2000), Santiago and Pelletier (2001), and Dewees and Schaefer (2001) for more information on remedial action planning for sites with contaminated sediments.

2.6 Confirmatory Monitoring and Assessment

Remediation of contaminated sediments is a relatively new field, which makes it difficult to precisely predict the outcome of remedial measures on an *a priori* basis. For this reason, it is important to conduct confirmatory sampling and analysis to determine if the remedial measures implemented have achieved the goals identified in the RAP. The procedures for conducting follow-up monitoring and evaluation are the same as those that would be applied during a DSI.

Chapter 3. Conducting a Preliminary Site Investigation

3.0 Introduction

A PSI should be conducted at all sites that are suspected of containing contaminated sediments (see Section 2.3 of Volume II). A PSI is typically conducted in two distinct phases. The first phase of the investigation (i.e., Stage I PSI) is intended to provide the information needed to more fully assess the potential for sediment contamination at the site and is conducted using existing information (Figure 2.3). The second phase of the investigation (i.e., Stage II PSI) is intended to provide information on nature, areal extent, and severity of sediment contamination at the site (Figure 2.4). The sediment chemistry data compiled during this process provide essential information for determining if contaminated sediments pose unacceptable risks to human health and/or to the environment. The recommended procedures for conducting Stage I and Stage II PSIs for sites with contaminated sediments are described in the following sections of this chapter.

3.1 Stage I Investigation

The first phase of a site-specific sediment quality assessment involves the collection and review of historical information on the site under consideration. Specifically, information is required on the current and historic activities and uses, accidents and spills of chemical substances, and practices and management relating to potential contamination at the site. It is also important to obtain information on land use patterns and on the location of effluent and stormwater discharges in the vicinity of the site to evaluate the potential for contamination from off-site sources. Existing water quality, effluent quality, and sediment quality data should also be obtained at this stage of the PSI. This type of information can be acquired by conducting reconnaissance visits to the site and by conducting interviews with key individuals, such as current and former owners, occupants, neighbors, managers, and employees of the facility. Government agency staff represents an important source of information on land use practices, designated water uses, contaminant sources, and ambient environmental conditions in the area.

The data collected during Stage I of the PSI should provide a basis for determining the nature and location of potential sources of contaminants to aquatic ecosystems. Information on the chemical composition of wastewater effluent discharges, on the chemicals used in the area, on the nature of spills and accidents, and on types of contaminants likely to be associated with non-point sources should be used to develop a preliminary list of COPCs at the site. The available information on the physical/chemical properties of the COPCs should then be used to identify the substances that are likely to partition into sediments (i.e., those with K_{ow}s of >3.5). These substances, then, form the basis of the refined list of COPCs with respect to sediment quality (Figure 2.3; see Chapter 3 of Volume I for more information on the identification of sediment quality issues and concerns).

During the Stage I PSI, information should be collected that helps to define the environmental management goals for the site. In many watersheds, for example, ecosystem goals and objectives have been established to guide resource management and restoration activities and to facilitate cooperation among the various participants. More specific goals and objectives for managing fine-grained sediments are established based on the legislative mandates of the responsible agencies. Information on the designated uses of sediment in the area is also needed to establish narrative management goals for the site (see Volume I of this guidance manual for more information on the establishment of ecosystem goals and objectives).

Evaluation of existing sediment chemistry data is a critical component of the site-specific sediment quality assessment process. Because sediment chemistry data are generated under various federal, tribal, state, and provincial programs for a variety of purposes, such data must be fully evaluated to determine their applicability to the sediment quality assessment that is being conducted. Some of the factors that should be considered in this evaluation include, sampling procedures, sample handling, transport, and holding procedures, analytical methods, toxicity testing methods, age of the data, geographic distribution of the sampling stations, and the analytes measured (i.e., relative to the refined list of COPCs generated). More information on the evaluation of candidate data sets for use in sediment quality assessments is provided in Appendix 4 of Volume III.

Together, the information collected in the first phase of the PSI should provide a basis for determining if sediment contamination is likely to represent an unacceptable risk to the environment or to human health. Sediment contamination should be suspected if toxic or bioaccumulative substances have been or are likely to have been released into the aquatic ecosystems at or near the site, or if ambient monitoring data indicate that sediment contamination has occurred at or near the site (i.e., based on exceedances of SQGs). If the minimum data requirements have been met and evaluation of these data indicates that sediment contamination is unlikely, then the need for further action at the site is generally obviated. If the minimum data requirements have not been met, then the outstanding data gaps should be identified and preparations for proceeding to the next stage of the process should be made. Depending on the nature and extent of contamination and on the complexity of the site, investigators may choose to conduct a Stage II PSI or move directly to the DSI.

3.2 Stage II Investigation

A Stage II PSI is conducted if the results of the Stage I investigation indicate that the sediments at the site are likely to be contaminated with toxic or bioaccumulative substances. The second stage of the PSI is intended to provide information on the nature, location, and magnitude of sediment contamination at the site. The existing sediment chemistry data, which were assembled in Stage I, may be used in this investigation if they provide suitable areal coverage, include the substances on the refined list of COPCs, and are of sufficient quality. However, additional sediment sampling is required when existing data are of insufficient quality or quantity to support an assessment of sediment quality at a site. The Stage II PSI consists of two main elements, including the data collection phase and the data interpretation phase of the investigation.

3.2.1 Data Collection

A Stage II PSI should be conducted when the results of the Stage I PSI indicate that sediments are likely to be contaminated by toxic and/or bioaccumulative substances, but insufficient data are available to fully evaluate the nature, areal extent, and severity of sediment contamination. Therefore, the first step in the Stage II PSI involves designing a sampling program that will provide the information needed to fill the data gaps identified during the Phase I PSI. Some of the key steps involved in developing a Phase II PSI SAP include:

- Map and describe the area to be sampled;
- Map location and extent of sediment depositional zones at the site;
- Map and describe the proposed sampling sites (including latitude and longitude);
- Describe the sediment sampling, handling, and storage procedures that will be used;
- List the chemical analytes that will be measured in sediment samples and associated data quality objectives; and,
- Describe the quality assurance procedures that will be used in the field and the laboratory (i.e., which should be included as an appendix to the SAP).

The first step in the development of a contaminated site sampling plan is to define the boundaries of the sediment sampling zone (SSZ). This step in the process is important because it defines the area that will be sampled to assess the areal extent of contamination and to identify sediment hot spots. For the purposes of conducting a Stage II investigation, it is recommended that the SSZ encompass the area that could, potentially, be contaminated due to releases of COPCs into receiving waters. The SSZ should extend from a point located well upstream of the discharge point or source area to a point located downstream of the first identified depositional area. It is important to note, however, that the SSZ does not, in any way, indicate the limit of responsibility or liability for contaminated sediments. Instead, it provides an operational definition of the area that is most likely to be contaminated by activities at the site and, hence, the area to be targeted by the Stage II PSI. Because additional sampling is required if significant contamination is detected near the boundary of the SSZ, it is usually most efficient to initially define the SSZ broadly (i.e., to avoid the need to remobilize a sampling team to collect additional data).

Development of a sampling grid is a critical element of the Stage II PSI sampling plan (i.e., identification of the location of sampling sites). As the sampling program needs to provide information on the spatial distribution of chemical contaminants at the site, it is important that the sampling design consider the results of the Stage I investigation. Two general sampling designs can be utilized at this stage of the site investigation, including stratified random sampling and biased sampling (Chapter 5 of Volume II). Stratified random sampling is recommended when the sediment contamination is suspected but little information is available on the specific location of potential contaminant sources. By comparison, a biased sampling design is recommended when the location of probable contaminant sources and downstream depositional areas are known, largely because identifying sediment hot spots is more likely (i.e., areas with elevated contaminant concentrations). Because characterizing the areal extent of contamination and identifying the location of hot spots is essential, investigators may collect samples from a relatively large number of sites and use analyses of indicator variables [e.g., total organic carbon (TOC), total petroleum hydrocarbons] to identify the samples that will be analyzed for a full suite of COPCs. In this way, it is possible to maximize the areal coverage of the site using screening chemistry and, in so doing, optimize the use of resources for chemical analyses. Importantly, the sampling program should be designed to determine the concentrations of COPCs in both surficial and deeper sediments.

The sampling and analysis plan should include descriptions of the methods that will be used to collect, handle, and store sediment samples that are collected for chemical analysis. Importantly, the collection, handing, and storage of sediment samples should follow established protocols, such as those developed by the ASTM (2001c) and USEPA (2001). To achieve this objective, everyone involved in the sampling program should receive training on these methods before initiating the sampling program. Additional guidance on sediment sampling is provided by Mudroch and McKnight (1991).

The procedures that will be used to identify and quantify the chemical substances in the sediment samples should also be described in the SAP. As a first step, a list of substances for chemical analysis should be compiled from the list of COPCs that was prepared in Stage I. This list should also include the variables that provide ancillary information for interpreting the resultant sediment chemistry data (e.g., TOC, AVS, NH_3, H_2S, Al, Li). Although the preferred analytical method for each analyte can also be specified in the SAP, establishing performance-based criteria for evaluating the analytical results may be preferable. Such criteria, which are articulated in the data quality objectives (DQOs) established for the investigation, provide analytical laboratories with a clear understanding of the project analytical requirements and, hence, a basis for selecting and/or refining methods that will assure that the project DQOs are met.

The procedures that will be applied to assure the overall integrity of the sampling program and the quality of the resultant data should be described in a QAPP (USEPA 1991a; 1991b; 1991c; 1991d; 2000c). The QAPP, which is typically included as an appendix to the SAP, should apply to both the field and laboratory components of the program. Some of the important elements that need to be contained in a QAPP include:

- Project organization and responsibilities;
- Personnel training and instruction;
- Data quality objectives, including the methods that will be used for assessing precision, accuracy, completeness, representativeness, and comparability of the data generated;
- Sampling procedures, including sampling equipment, decontamination of equipment, collection of field duplicates, generation of field blanks, positional data collection, sample containers, sample identification and labeling, sample preservation and holding times, field documentation, and field data sheets;
- Sample custody and transportation, including field custody procedures, chain-of-custody documentation, sample packaging and transport, and laboratory log-in procedures and documentation;
- Analytical methods, including target detection limits, accuracy, and precision for each analyte (i.e., DQOs);
- Data management, validation, analysis, and reporting procedures; and,
- Quality assurance report preparation.

Implementation of a focused, well-designed monitoring program will ensure that the resultant sediment chemistry data will support a defensible sediment quality assessment. More information on the design of sediment quality sampling programs is provided in Chapter 5 of Volume II, while the elements of sampling and analysis plans are described in Appendix 3 of Volume II.

3.2.2 Data Interpretation

Interpretation of the data collected in the Stage II PSI should be conducted in three steps. As a first step, the quality assurance information collected during the sampling program should be reviewed in light of the acceptance criteria established in the QAPP (see Appendix 3 of Volume II for more details). This initial evaluation provides a basis for assessing the validity of the resultant data and determining if additional sampling is required. Any data gaps that are identified should be documented and used to support the design of the DSI, if required.

In the second step of the data analysis, the sediment chemistry data are compared to the numerical SQGs that have been established to protect and/or restore the sediment uses at the site. The results of this analysis provide a basis for identifying the contaminants that are present in sediments at concentrations that may be sufficient to impair one or more beneficial uses of the aquatic ecosystem. Application of mean SQG-quotients provides a basis for estimating the probability that individual sediment samples would be toxic to sediment-dwelling organisms (MacDonald *et al.* 2000; USEPA 2000d). In addition, the results of the Stage II PSI provide the data needed to ascertain the locations of sediment hot spots and to assess the relative hazards posed by each COPC (i.e., by considering the degree to which ambient concentrations exceed the SQGs).

While exceedances of the SQGs provide strong evidence of chemical contamination, it should be recognized that all or a portion of the exceedances may be associated with elevated background concentrations. For this reason, the third step of the data analysis should involve comparison of the data from the site to regional background concentrations and/or contemporary background concentrations of each COPC. The substances that exceed both the SQGs and background levels should be considered to be the contaminants of concern (COCs) at the site. Some of the methods for determining background concentrations of metals and organic contaminants are described in Appendix 2 of Volume III of this guidance manual. Further information on the interpretation of sediment chemistry data is also provided in Volume III.

Chapter 4. Conducting a Detailed Site Investigation

4.0 Introduction

A detailed site investigation (DSI) is required if the results of the preliminary site investigation (PSI; which is conducted using sediment chemistry data) indicate that sediments are sufficiently contaminated to impair the beneficial uses of the aquatic ecosystem (i.e., pose unacceptable risks to sediment-dwelling organisms, and aquatic-dependent wildlife, or human health). The information collected and compiled during the PSI should be used to design the DSI. As the PSI was conducted to evaluate the nature, magnitude, and location of sediment contamination at the site, the results of the investigation should provide the information needed to identify which substances occur in sediments at harmful levels (i.e., in excess of the SQGs), describe the range of concentrations of priority substances, and identify the locations that contain elevated levels of sediment-associated contaminants. Importantly, the PSI should also provide essential background information on the site, such as the location of contaminant discharges and spills. As such, the PSI provides critical information for designing a well-focused DSI.

The DSI is designed to provide the information needed to assess risks to sediment-dwelling organisms, wildlife, and human health associated with exposure to contaminated sediments. In addition, the DSI should provide the necessary and sufficient information to support the evaluation of remedial alternatives and the development of a RAP. Because the results of the DSI will be used directly to support sediment management decisions, the scope of this investigation will necessarily be broader than that of a PSI. More specifically, the DSI should be designed to answer four main questions, including:

- Does the presence of COPCs in whole sediments and/or pore water pose an unacceptable risk to the receptors under consideration (i.e., sediment-dwelling organisms, aquatic-dependent wildlife, or human health)?
- What is the nature, severity, and areal extent of the risk to each receptor under consideration?
- Which COPCs are causing or substantially contributing to the risk to the receptor under consideration?

- What are the concentrations of COPCs, by media type, that are associated with negligible risk to the receptor under consideration?

The DSI consists of two elements, including the data collection phase and the data interpretation stage. The following sections of this chapter provide an overview of the recommended procedures for conducting a DSI. More specific guidance on ecological and human health risk assessments relative to contaminated sediments are described in other documents (e.g., Ingersoll *et al.* 1997; Landis *et al.* 1997; USEPA 1998b). More detailed guidance on the design of sampling programs and the development of sampling and analysis plans is provided in Chapter 5 and Appendix 3 of Volume II, respectively.

4.1 Collection of Sediment Quality Data

The development of a DSI SAP and associated QAPP represent essential steps in the overall data collection process. Some of the key steps involved in developing a SAP for the DSI include (see Chapter 5 of Volume II for more information):

- Map and describe the area to be sampled (i.e., sediment sampling zone; SSZ);
- Determine the data requirements for ecological and human health risk assessments;
- Map and describe the proposed sampling sites (including latitude and longitude);
- Describe the sediment sampling, handling, and storage procedures that will be used for obtaining sediment samples for chemical analysis;
- List the chemical analytes that will be measured in sediment samples and associated data quality objectives;
- Describe the sediment sampling, handling, and storage procedures that will be used for obtaining sediment samples for toxicity and bioaccumulation testing;
- Describe the toxicity tests that will be conducted on the sediment samples, including the associated description of the selected metrics (e.g., survival and growth);

- Describe the procedures that will be used to assess bioaccumulation;
- Describe the procedures that will be used for sampling the benthic invertebrate community, including associated descriptions of the selected metrics (e.g., benthic index); and,
- Describe the quality assurance procedures that will be used in the field and the laboratory (i.e., which should be included as an appendix to the sampling plan).

Definition of the SSZ is the first step in the development of a sampling plan for the DSI. As the DSI is designed to provide further information on the areal extent of sediment contamination, including the extent to which COPCs have been transported to adjoining properties, the SSZ may be larger than that identified in the PSI. For example, if significant contamination was found near the boundaries of the SSZ for the PSI, then the SSZ for the DSI should be expanded substantially to support characterization of the areal extent of contamination. While near-term sampling costs are likely to be it less if the SSZ for the DSI is relatively small, additional sampling may be required if the results of the DSI indicate that contaminated sediments occur at or near the boundaries of the SSZ. Therefore, it may be more cost-effective to err on the side of inclusiveness when defining the SSZ for the DSI (i.e., making it larger than what seems absolutely necessary). As was the case for the PSI, the size of the SSZ does not, in any way, indicate the limit of responsibility or liability for contaminated sediments. Instead it provides an operational definition of the area that is most likely to be contaminated by activities at the site.

The second step in the design of a DSI sampling plan is to develop a sampling grid (i.e., identify the location of sampling sites). As the DSI needs to provide information on the specific areas, depths, and magnitude of contamination at the site and in nearby areas, it is important to review the results of the PSI to identify potential hot spots with respect to sediment contamination. In general, a biased sampling design is preferred for the DSI because it can be used to focus sampling effort on the areas that are most likely to be contaminated (i.e., by conducting targeted sampling to delineate the location and extent of hot spot areas). Within the original SSZ (i.e., the area sampled during the PSI), intensive sampling should be conducted in the vicinity of sediment hot spots to confirm the results of the PSI, to determine the areal extent of contamination at each hot spot, and to identify gradients in contaminant concentrations. Outside the original SSZ, biased sampling should be used to target potential hot spots (i.e., near the contaminated areas within the original

SSZ) and random sampling should be used to investigate the potential for contamination in other areas.

Importantly, the DSI sampling program should be designed to determine the concentrations of COPCs in both surficial and deeper sediments. The sampling plan should identify the location of each site that will be sampled, with decision criteria also provided in the event that sampling certain sites is not feasible. As the mobilization/demobilization costs associated with sediment sampling can be substantial, it may be prudent to collect and archive samples from additional locations during the DSI. This makes it possible to, for example, analyze samples collected 10 m from a hot spot if the samples collected 5 m from that hot spot show significant contamination. In this way, the costs associated with chemical analyses can be minimized. However, attention needs to be paid to acceptable holding times to ensure that only high quality data are generated (ASTM 2001a; 2001c).

The sampling plan should include descriptions of the methods that will be used to collect, handle, and store sediment samples. These instructions are particularly important in the DSI because sediment samples are likely to be collected for several purposes, including chemical analysis, toxicity testing, bioaccumulation assessment, and/or benthic invertebrate community analyses. As one of the objectives of the DSI is to confirm that the contaminated sediments are actually toxic to sediment-dwelling organisms, it is critical that sediments be collected in a manner that facilitates the generation of matching sediment chemistry and biological effects data (i.e., by preparing splits of homogenized sediment samples). The collection, handing, and storage of sediment samples needs to follow established protocols, (ASTM 2001a; 2001b; 2001d; USEPA 2001). To achieve this objective, everyone involved in the sampling program should receive specialized training on these methods before starting the sampling program.

In addition to the foregoing considerations, development of the DSI sampling program should consider additional factors that apply to each of the key indicators of sediment quality conditions, including sediment chemistry data, sediment toxicity data, benthic invertebrate community assessments, and bioaccumulation assessments (Krantzberg *et al.* 2000). Some additional considerations that should be taken into account in designing the DSI sampling program are discussed in the following sections. Additional guidance on each of these indicators is provided in Volume III.

4.1.1 Sediment Chemistry

The procedures that will be used to identify and quantify the chemical substances in the sediment samples should be described in the sampling and analysis plan (see Chapter 2 of Volume III for more information). As a first step, a list of substances for chemical analysis should be compiled using the results of the PSI and other considerations (e.g., substances used to calculate mean SQG-quotients). This list should also include the variables that provide ancillary information for interpreting the resultant sediment chemistry data (e.g., TOC, AVS, Al, Li). The preferred analytical method for each analyte can also be specified in the sampling plan; however, it may be more prudent to let the analytical laboratory select the methods based on the data quality objectives for the project. Clearly articulating the data quality requirements (i.e., accuracy, precision, and detection limits) to the laboratory personnel at the outset of the project is likely to minimize the potential for problems later.

The procedures that will be used to assess the biological effects associated with contaminated sediments should also be included in the sampling plan. Biological assessment is an essential tool for evaluating sediment quality conditions at contaminated sites because it provides important information for interpreting sediment chemistry data. The five types of biological assessments that are commonly conducted at sites with contaminated sediments include toxicity testing, benthic invertebrate community assessments, bioaccumulation testing, fish health, and fish community structure. More detailed information on each of these indicators is presented in Volume III of this guidance manual.

4.1.2 Toxicity Testing

The selection of appropriate toxicity tests is an important element of the overall biological assessment process (Chapter 3 of Volume III). Provision of guidance in this area is particularly important because various regulatory programs (e.g., dredged material analysis programs) have developed conventions that may not be directly applicable for DSIs at sites with contaminated sediments. Because sediment-dwelling organisms are exposed to contaminated sediments for extended periods, at least one chronic toxicity test on a sensitive sediment-dwelling organism, in which sub-lethal endpoints are measured, should be included in the DSI. Although several such tests are available, the 28-day whole-sediment toxicity test with the amphipod, *Hyalella azteca*, is likely to be relevant in many situations. Survival and growth are the endpoints measured in this toxicity test (USEPA 2000a; ASTM 2001a).

Acute toxicity tests can also be used to assess the toxicity of contaminated sediments to sediment-dwelling organisms. However, the results of such tests must be interpreted with caution due to the potential for obtaining false negative results (i.e., erroneous concluding that contaminated sediments are unlikely to adversely affect sediment-dwelling organisms). Amphipods (*Hyalella azteca*) and midges (*Chironomus riparius* and *Chironomus tentans*) are the invertebrate species most commonly used in acute toxicity tests (ASTM 2001a; USEPA 2000a). Pore water toxicity assessments can also be used to provide further information on the toxicity of contaminated sediments. There is no standardized test for assessing the effects of pore water in freshwater sediments; however, bacteria, amphipods, daphnids, and other species have been used successfully to assess toxicity in this medium (ASTM 2001b).

4.1.3 Benthic Invertebrate Community Assessments

A wide variety of techniques have been used to evaluate the effects of contaminated sediments on benthic invertebrate communities (see Rosenberg and Resh 1993; Ingersoll *et al.* 1997). These techniques can be classified into four general categories based on the level of organization considered (Chapter 4 of Volume III). The assessments are reliant on measurements of endpoints that are relevant to the following organizational scales:

- Individual (e.g., morphological changes, biomarkers);
- Population (e.g., abundance of keystone species; population size structure);
- Community structure (e.g., benthic index, multivariate analyses); and,
- Community function (e.g., energy transfer, functional groups).

All of the various measurement endpoints are evaluated based on departure from an expected or predicted condition (such as observations made at appropriate reference sites). Uncertainty in the application of these techniques stems from incomplete knowledge of the system (i.e., what represents normal conditions); systematic error in the method being used; and, the sampling scale selected (Ingersoll *et al.* 1997). Of the organization scales evaluated, the measurement endpoints which provide information on the status of invertebrate populations and community structure were considered to be the most reliable (Reynoldson *et al.* 1995; Ingersoll *et al.* 1997).

4.1.4 Bioaccumulation Assessments

Bioaccumulation assessments are used to evaluate the extent to which sediment-associated COPCs accumulate in the tissues of sediment-dwelling organisms (Chapter 5 of Volume III; ASTM 2000d). In laboratory bioaccumulation tests, individuals of a single species are exposed to field-collected sediments under controlled conditions. After an established period of exposure (usually 28 days), the tissues of the test species are analyzed to determine the concentrations of COPCs. Bioaccumulation is considered to have occurred if the final concentrations of the COPCs in tissues exceed the concentrations that were measured in tissue at the beginning of the test or in the tissues of organisms exposed to control sediments. In field investigations, sediment-dwelling organisms may be collected at the site under consideration and their tissues analyzed for the COPCs. Alternatively, organisms can be transplanted to the site from an uncontaminated location and the tissues analyzed for COPCs after a predetermined exposure period. Modeling procedures can also be used to estimate the concentrations of contaminants that could accumulate in the tissues of aquatic organisms as a result of exposure to contaminated sediments.

An expert panel evaluated the uncertainty associated with all four of the procedures established for conducting bioaccumulation assessments (Ingersoll *et al.* 1997). The results of this evaluation indicate that bioaccumulation is a highly variable endpoint that primarily provides information on exposure to contaminants. It is particularly useful for determining the bioavailability of sediment-associated contaminants. Of the four approaches evaluated, laboratory assessments were considered to be the most reliable and are recommended for assessing bioaccumulation potential at contaminated sites. The preferred test species for freshwater bioaccumulation assessments is the oligochaete (*Lumbriculus variegatus)*; however many other species may be used in this application (see ASTM 2001d). It should be noted that such data do not necessarily provide a direct means of estimating tissue residues in the field. For this reason, it is also recommended that the tissues of resident species also be collected and analyzed to provide a basis for assessing hazards to human health and aquatic-dependent wildlife species (i.e., by comparing measured tissue concentrations to tissue residue guidelines).

4.1.5 Other Tools for Assessing Sediment Quality Conditions

While sediment chemistry, sediment toxicity, benthic invertebrate community structure, and bioaccumulation data represent the primary tools for assessing sediment quality conditions in freshwater ecosystems, there are a number of other tools that can be used to support the sediment quality assessment process. For example, in certain circumstances it may be necessary to identify the substances that are causing or substantially contributing to the effects observed in the investigation. In these cases, spiked sediment toxicity tests and/or toxicity identification evaluation (TIE) procedures can be used to help identify the putative causal agents. In addition, numerical SQGs can be used to assist in the identification of the substances that are causing or substantially contributing to sediment toxicity. Furthermore, various data analytical approaches, such as multiple regression analysis and principal components analysis, can be applied to identify the substances that are most directly linked to the toxic effects observed in field collected samples. Some of these tools and their applications are briefly described in Chapter 7 of Volume III.

4.1.6 Quality Assurance Project Plan

The sampling and analysis plan for the DSI should include a QAPP that applies to both the field and laboratory components of the program. Some of the important elements that need to be contained in a QAPP for a DSI include:

- Project organization and responsibility;
- Personnel training and instruction;

- Quality assurance objectives and methods for assessing precision, accuracy, completeness, representativeness, and comparability of the data generated;
- Sampling procedures, including sampling equipment, decontamination of equipment, collection of field duplicates, generation of field blanks, collection of positional data, sample containers, sample identification and labeling, sample preservation and holding times, field documentation, and field data sheets;
- Sample handling and preparation procedures for each media type and purpose (i.e., chemistry, toxicity testing, etc.);
- Sample custody and transportation, including field custody procedures, chain-of-custody documentation, sample packaging and transport, and laboratory log-in procedures and documentation;
- Analytical methods, including target data quality objectives;
- Toxicity testing procedures, including descriptions of negative controls, positive controls, and reference samples, and associated criteria for data acceptance;
- Bioaccumulation testing procedures and associated criteria for data acceptance;
- Benthic invertebrates identification and counting procedures and associated criteria for data acceptance;
- Data management, validation, analysis, and reporting procedures; and,
- Quality assurance report preparation.

Implementation of a well-designed sampling program is likely to provide the data needed to conduct a comprehensive assessment of sediment quality conditions at the site. More information on the design of sediment quality sampling programs is provided in Chapter 5 of Volume II, while the elements of sampling and analysis plans are described in Appendix 3 of Volume II.

4.2 Data Interpretation

Interpretation of the data collected in the DSI is more involved than the interpretation of Stage II PSI data. As was the case for the PSI, the review and evaluation of the quality assurance information (i.e., in light of the acceptance criteria that were established in the QAPP) represents the first stage of the data interpretation process. This initial evaluation provides a basis for assessing the validity of the resultant data and determining if additional sampling is required.

In the second step of the data analysis process, the data collected in the DSI are compiled and used to assess exposures to contaminated sediments, the effects of contaminated sediments on ecological receptors and human health, and the risks posed by contaminated sediments to beneficial uses of the aquatic ecosystem. The objectives of the exposure assessment are to identify the receptors at risk, describe the relevant exposure pathways, and determine intensity and areal extent of the exposure to COPCs. Sediment chemistry data and/or pore water chemistry data may be used, in conjunction with applicable benchmarks (e.g., SQGs, water quality criteria, background levels), to identify the areas, depths, and degree of contamination at the site and in nearby areas. If significant contamination (i.e., > SQGs) is observed at or nearby the boundaries of the SSZ (either in surficial sediments or at depth), then additional sampling may be required to fully characterize the spatial extent of contamination.

The primary objective of the effects assessment is to describe the nature and severity of effects that are being caused by contaminated sediments. Sediment chemistry data can also be used in the effects assessment to estimate the probability that specific types of effects would be associated with exposure to contaminated sediments (i.e., using the dose-response relationships established for individual COPCs or groups of COPCs; e.g., Swartz 1999; MacDonald *et al.* 2000; USEPA 2000d). Additionally, the results of the toxicity tests can be used to determine if sediments with elevated concentrations of COPCs (i.e., relative to the SQGs) are toxic to aquatic organisms. Contaminants may be present in relatively unavailable forms or other factors may be mitigating toxicity at the sites that have elevated chemical concentrations but are not toxic to sediment-dwelling organisms. The results of benthic invertebrate community assessment can also be used to evaluate the effects of contaminated sediments on sediment-dwelling organisms. Agreement among the three measures of adverse biological effects (i.e., the SQGs, toxicity tests, and benthic assessments) provides strong evidence for identifying the specific areas and sediment depths that are contaminated to levels that are adversely affecting or have the potential to adversely affect sediment-dwelling organisms (Chapter 7 of Volume III).

The data collected in the DSI can also be used to assess the hazards associated with bioaccumulative substances at the site. In this assessment, the results of laboratory bioaccumulation tests provide a basis for identifying which substances are bioavailable and have the potential to bioaccumulate in the food web. The results of chemical analyses of biological tissues collected at the site can then be used to confirm the results of the laboratory bioaccumulation tests. To evaluate the potential effects of bioaccumulative substances, the tissue residue data can be compared to the tissue residue standards established for the protection of wildlife and human health. In this way, the chemicals and the locations that pose the greatest hazards to human health and wildlife can be identified. Integration of the results of the exposure and effects assessments provides a basis for estimating risks to ecological receptors associated with exposure to contaminated sediments. A matrix of data interpretation tools relating to various ecological impairments associated with sediment contamination is provided in Table 4.1 (Krantzberg *et al.* 2000)

The results of the investigations that are conducted during this phase of the project should be compiled and collated into a comprehensive DSI report. This report should include the objectives of the investigation, provide a summary of the background information on the site, a description of the study approach, a summary of the existing information on sediment quality conditions at the site, a description of the methods that were used to generate the new data, a summary of the results of the investigations, and a discussion of the interpretation of the resultant data. All of the data collected during the investigation should be compiled in appendices that facilitate access to and/or re-analysis of the information. The reader is directed to Volume III of this guidance manual for more information on the interpretation of data on individual and multiple indicators of sediment quality conditions generated during the DSI.

Chapter 5. Developing Sampling and Analysis Plans for Assessing Sediment Quality Conditions

5.0 Introduction

A primary goal of most sediment quality assessment programs is to determine if the presence of toxic chemicals in sediment is adversely affecting sediment-dwelling organisms. When sediments contain bioaccumulative substances, a primary goal of assessment programs is to determine if these contaminants are accumulating in the tissues of aquatic organisms to such an extent that they pose a hazard to sediment-dwelling organisms, aquatic-dependent wildlife, or human health. More specifically, sediment assessments can be used to:

- Determine the relationship between toxic effects and bioavailability;
- Investigate interactions among chemicals;
- Compare the sensitivities of different organisms;
- Determine spatial and temporal distribution of contamination;
- Evaluate hazards of dredged material;
- Measure toxicity as part of product licensing or safety testing;
- Rank areas for clean up; and,
- Evaluate the effectiveness of remediation or management practices.

Considering the diversity of reasons for conducting sediment quality assessments and the variety of programs under which such assessments can be implemented (see Appendix 1 of Volume II), it is not feasible to provide guidance on the design of sediment quality assessments that applies uniformly to every application. Therefore, this chapter is intended to compliment the general guidance that was provided on preliminary and detailed site investigations (i.e., PSIs - Chapter 3; DSIs - Chapter 4 of Volume II) by identifying the essential elements of SAPs for assessing contaminated sediments, including:

- Background information on the site;
- Objectives of the sediment assessment program;
- Field sampling methods;
- Sample handling procedures;
- Technical oversight and auditing;
- Quality assurance and quality control procedures;
- Data validation and quality control;
- Data evaluation and validation
- Data analysis, record keeping, and reporting;
- Health and safety; and,
- Responsibilities of the project team members.

Each of these elements of SAPs are briefly described in the following sections of this chapter (see Table 5.1 for a sediment sampling and analysis plan outline and checklist). More detailed information on several key issues related to the design of sampling programs for assessing contaminated sediments in provided in Appendix 3 of Volume II.

5.1 Background Information

Development of a sampling and analysis plan that explicitly addresses the objectives of the sediment quality assessment program requires background information on the site under investigation. The types of background information that should be collected to inform the design of the assessment program include (WDOE 1995):

- Site history;
- Regulatory framework (e.g., NPDES, NRDA, CERCLA; see Appendix 1 of Volume II);

- Results of previous investigations (including data on physical, chemical, and biological conditions);
- Location and characteristics of historic and current contaminant sources in the vicinity of the site, including stormwater discharges, wastewater discharges, hazardous waste storage/disposal, and, hazardous material spills;
- Location of depositional areas; and,
- Designated water uses.

Collectively, this information provides a basis for identifying the sediment quality issues and concerns at the site, including the COPCs and areas of potential concern (Chapter 3 of Volume I). This information also supports the design of a sampling program that characterizes the nature, extent, and severity of sediment contamination.

Review of available historical data is important both in the initial station selection process and in subsequent data interpretation. Local experts should be consulted to obtain information on site conditions and on the origin, nature, and degree of contamination. Other potential sources of information include government agency records, municipal archives, harbor commission records, news media reports, past geochemical analyses, hydrographic surveys, and bathymetric maps. Potential sources of contamination should be identified and their locations noted on a map or chart of the proposed study area. An inspection of the site is recommended when developing a study plan, in order to assess the completeness and validity of the collected historical data, and to identify any significant changes that might have occurred at the site since the historical data were collected. Conducting some reconnaissance sampling to refine the sampling design is also useful (i.e., which may be focused on particle size distribution, TOC, or some other suitable indicators of chemical contamination). Reconnaissance sampling is particularly helpful in defining appropriate station locations for targeted sampling or to identify appropriate strata for stratified sampling or subareas for multistage sampling.

5.2 Objectives of the Sediment Investigation

The objectives of sediment quality assessments can vary markedly depending on the regulatory program under which they are conducted. Descriptions of the types and objectives of sediment quality assessments that are being conducted under various regulatory programs are provided in Appendix 1 of Volume II). In turn, the objectives of the assessment play a central role in dictating the design of the investigation. For example, certain investigations may be explicitly designed to assess trends in environmental quality conditions, while others are designed to evaluate the status of sediment quality conditions. Such differences in objectives need to be reflected in the sampling design that is described in the SAP.

Assessments of trends in environmental quality conditions typically focus on evaluating either spatial trends or temporal trends. In assessments of spatial trends, sampling programs may be designed to facilitate the collection and analysis of sediment samples from a large number of stations within the study area. In contrast, assessments of temporal trends typically involve repeated collection of sediment samples from a number of stations at pre-determined time intervals. Both types of investigations typically focus on chemical analysis of the selected media types (e.g., whole sediments, pore water); however, other indicators of sediment quality conditions may be employed in trend assessments.

The designs of sampling programs to assess the status of sediment quality conditions tend to differ markedly from those that are focused on trend assessment. Such sampling programs are typically undertaken to evaluate the effects of contaminated sediments on the attributes of key groups of receptors (e.g., sediment-dwelling organisms, aquatic-dependent wildlife, and/or human health, which are often referred to as assessment endpoints). The measurement endpoints (i.e., indicators of sediment quality conditions that are actually measured) that are ultimately included in the sampling program are based on the selected assessment endpoints and the exposure pathways that are most relevant for the receptor groups under consideration. As such, the sampling program designs are more likely to include sediment toxicity, benthic invertebrate community, and bioaccumulation assessments, as well as sediment and pore water chemistry. In addition, it is necessary to include control and reference sediments in these types of investigations to facilitate interpretation of the resultant data (Appendix 3 of Volume II). Controls are used to evaluate the acceptability of the test, whereas testing of reference sediments provides a site-specific basis for evaluating toxicity of the test sediments. Comparisons of test sediments to multiple reference or control sediments representative of the physical characteristics of the test sediment (i.e., grain size, organic carbon) may be useful in these evaluations.

In some cases, sediment quality assessments are conducted to determine if sediments are suitable for open water disposal. In these cases, tiered assessment techniques may be applied to obtain the requisite data to support sediment management decisions. Such tiered assessment frameworks may rely primarily on sediment chemistry data in the earlier tiers of the assessment, while biological testing is used more extensively in later tiers (USEPA and USACE 1998b).

Sediment quality assessments can also include an evaluation of the toxicity of an individual contaminant or mixtures of contaminants on selected receptors. In these cases, known quantities of the substance or substances under investigation are spiked into whole sediments. Toxicity tests are then conducted to evaluate the effects of each exposure concentration on the selected receptor (e.g., amphipods, chironomids) and test endpoint (e.g., survival, growth). Evaluation of the resultant data provides a basis for determining the lethal concentrations (e.g., LC_{50}) or effective concentrations (e.g., EC_{50}) of the substance or substances in sediments. Such an investigation would require a negative control sediment, a positive control, a solvent control, and several concentrations of sediment spiked with a chemical (ASTM 2001a; USEPA 2000a).

If the purpose of the study is to conduct a reconnaissance field survey to identify the portions of the study area that require further investigation, the experimental design might include only one sample from each station to allow for sampling a larger area. The lack of replication at a station usually precludes statistical comparisons such as analysis of variance (ANOVA), but these surveys can be used to identify stations for further study or may be evaluated using regression techniques (ASTM 2001a; USEPA 2000a).

More information on the selection of sediment quality indicators, metrics, and targets for assessing contaminated sediments, based on the objectives of the sampling program, is provided in Chapter 5 of Volume I and in Chapters 2 through 5 in Volume III.

5.3 Field Sampling Methods

The purpose of the sampling program is to collect undisturbed sediment samples from one or more stations within the assessment area. Such samples are typically collected to support physical-chemical analyses, toxicity testing, benthic invertebrate community assessments and/or bioaccumulation assessments. To assure that field personnel are adequately prepared to collect the required sample volumes from each sampling station, it is essential that the methods that will be used to collect sediment samples in the field be fully described in the project SAP. The selection of such methods for collecting sediment samples will be influenced by a variety of factors, including:

- Sampling design;
- Type of sampling platforms available;
- Location of and access to the sampling stations;
- Physical characteristics of the sediments;
- Number of sites to be sampled;
- Water depth;
- Number and experience of personnel; and,
- Budget.

In general, the sediment samplers that are used in most freshwater sediment assessments can be classified into two major categories, grab samplers and corers (USEPA 2001; ASTM 2001c). Some of the commonly utilized grab samples include Birge-Ekman grab samplers (standard and petite), Ponar grab samplers (standard and petite), Van Veen grab samplers (standard and large), and Shipek grab sampler. Hand corers, single-gravity corers, multiple-gravity corers, box corers piston corers, and vibratory corers represent the primary classes of sediment corers that are currently available. Specific methods are also available for obtaining pore water samples. The advantages and disadvantages of various sediment samplers are described in Table 5.2 (WDOE 1995). The minimum sample volumes to support physical-chemical analyses and toxicity testing are presented in Table 5.3.

To enhance comparability of the resultant data, the same method should be used to collect samples from all of the sampling station within the assessment area, whenever practicable. However, the need to collect both surficial and deeper sediments may preclude this possibility in certain circumstances. The reader is directed to Mudroch and McKnight (1991), Mudroch and Azcue (1995), USEPA (2001), and ASTM (2001c) for more information on the collection of sediment samples.

5.4 Sample Handling Procedures

The sediment samples that are collected in the field are likely to be subjected to a physical, chemical, and/or biological testing to support the overall sediment assessment program. The methods that are applied for handling, preserving, and transporting, and storing the samples are dependent on the objectives of the study and the type of testing to which each sample will be subjected. In cases where data on multiple indicators of sediment quality conditions are to be generated, the importance of synoptically-collected sediment samples cannot be over stated (i.e., collecting sufficient volumes of sediment at each station to facilitate the preparation of a subsample for toxicity testing and subsamples for chemical analysis from a single, homogenized sediment sample). Appropriate methods for handling, transporting, and storing sediment samples for chemical analysis and toxicity testing are presented in ASTM (2001c) and USEPA (2001). The recommended storage temperatures and maximum holding times for physical-chemical analyses and sediment toxicity testing are presented in Table 5.4. Recommended chain-of custody procedures and methods for delivering sediment samples to analytical laboratories are summarized in WDOE (1995).

5.5 Technical Oversight and Auditing

In many cases, the field component of the sediment quality assessment is conducted by contractors who have ready access to sampling vessels and equipment. While these contractors may have a good deal of experience in the collection of environmental media, there may be unique aspects of the sediment quality assessment that require special attention in the field (e.g., collection of matching samples for chemical analysis, toxicity testing, and benthic community structure). For this reason, it is recommended that one or more individuals be assigned the task of providing technical oversight and auditing of all aspects of the field program. This individual would be responsible for reviewing the SAP (and associated QAPP), overseeing the training of the field crew, confirming sample locations prior to sampling, observing sample collection procedures, documenting any inconsistencies and errors that are observed, assuring that corrective actions are taken, and documenting sample handling and transport procedures.

5.6 Quality Assurance Project Plan

A QAPP, which outlines specific steps that will be used to perform the study, should be prepared in advance of collecting samples and appended to the SAP. The scope of the QAPP is dependant on the specific objectives of the study. Some of the preliminary issues that need to be considered prior to preparing this plan include:

- Defining the potential problem that needs to be addressed;
- Determining resources that are available for the project;
- Reviewing the existing information and identifying the specific objectives for the study; and,
- Determining the data that are likely to be needed to fulfill the project objectives.

Detailed guidance on the development of QAPPs is available from a number of sources. First, USEPA has developed a quality system to assure the quality of data that are collected, generated, and used under its programs. As part of this program, USEPA has developed a number of training course on QA/QC activities, including both generic and specialized training (see www.epa.gov/quality/trcourse.html for more information). In addition, USEPA has published a number of guidance documents to support the development of QAPPs for sediment quality and related assessments (see USEPA 1991a; 1991b; 1991c; 1991d; 1993; 1994a; 1998a; 1999a for further information). Furthermore, similar guidance documents have been established to support certain state government programs (e.g., WDOE 1995). The quality control procedures that have been identified by WDOE (1995) for organic analyses, metal analyses, conventional analyses, and freshwater sediment toxicity testing are presented in Tables 5.5, 5.6, 5.7, and 5.8, respectively. ASTM (2001a; 2001b; 2001c) and USEPA (2000a) provide more recent guidance on test conditions for conducting whole-sediment toxicity tests.

5.7 Data Evaluation and Validation

Data evaluation and validation represents an essential component of the overall sediment assessment process. The results of this step of the process determine which data can be reliably used in the assessment. The project data quality objectives, which are included in the QAPP, provide functional guidance for evaluating data quality (USEPA 1998a). Procedures for validating the data generated during the assessment should be determined on an *a priori* basis and included in the SAP. In general, there are five factors that are considered in the evaluation of physical, chemical, and biological data, including:

- Precision
- Accuracy;
- Representativeness;
- Completeness; and,
- Comparability.

Precision, accuracy, representativeness, completeness, and comparability (PARCC) parameters are indicators of data quality. PARCC goals are established for the site characterization to aid in assessing data quality. More information on each of the five indicators of data quality is provided in Appendix 3 of Volume II.

5.8 Data Analysis, Record Keeping, and Reporting

Data analysis, record keeping, and reporting represent essential elements of a sediment quality assessment. For this reason, the procedures that are to be used to support the assessment should be described in the SAP. The recommended procedures for interpreting individual and multiple lines of evidence are presented in Chapter 7 of Volume III. Additional information on data analysis, record keeping, and reporting is provided in WDOE (1995).

5.9 Health and Safety Plan

It is recommended that a comprehensive health and safety plan be included in the project SAP. The health and safety plan should cover all aspects of worker safety during the collection, handling, transport, and analysis of sediment samples (USEPA 2001; ASTM 2001c). The health and safety plan should include a list of the tasks to be performed, a listing of key personnel and responsibilities, a description of the chemical and physical hazards associated with the site, and an analysis of the health and safety risks associated with each task. In addition, the plan should include an air monitoring plan, a description of the personal protective equipment that will be used for each task (including contingencies), procedures for decontaminating personnel and equipment, procedures for disposing of contaminated media and equipment, a description of safe work practices, and standard operating procedures. Finally, a contingency plan, personnel training requirements, a medical surveillance program, and record-keeping procedures should be included in the health and safety plan. The members of the sampling team should be reminded about key health and safety issues related to sampling and sample preparation prior to initiating activities on each day of the sampling program.

5.10 Project Schedule

A project schedule represents an important component of the SAP. The project schedule should clearly specify when each element of the sediment quality assessment will be completed. Some of the activities that should be included in the project schedule include field mobilization, field sampling (including time for sampling sub-areas and sequencing for sampling each station), field demobilization, shipment of samples to laboratories, initiation and completion of physical, chemical, and biological analyses, initiation and completion of data validation, completion of data reports, and completion of interpretive reports. Because laboratories may not be available on demand, it is important to consider holding times for chemical and biological samples when developing sampling schedules for the field program. In addition to supporting the technical aspects of the program, a detailed project schedule is likely to support the administrative components of the process (i.e., funding, contracting, etc.).

5.11 Project Team and Responsibilities

The SAP should include a brief description of the responsibilities of each member of the project team. In general, the project team will include a project manager, a number of scientists that are responsible to various field and laboratory components of the project, and a number of field and laboratory technicians. In addition, a QA/QC coordinator, database coordinator, data analysts, and other specialists are likely to play important roles during the planning and implementation of the investigation.

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Appendices

Appendix 1 Types and Objectives of Freshwater Sediment Quality Assessments

A1.0 Introduction

Discharges of toxic and bioaccumulative substances into aquatic ecosystems have been reduced in the last 30 years. Nevertheless, persistent contaminants in sediments continue to pose potential risks to human health and the environment (USEPA 1994a; USEPA 1997a). Elevated concentrations of contaminants in bottom sediments and associated adverse effects have been documented throughout North America. Contaminated sediments have been identified as a significant environmental concern at 42 of the 43 Great Lakes Areas of Concern (AOCs; IJC 1988; 1997) and at numerous other sites in the United States and Canada.

The extent of sediment contamination and associated adverse effects in the United States have been summarized in the USEPA National Sediment Inventory (USEPA 1997a). The results of this assessment indicate that substances such as metals, PAHs, PCBs, dichlorodiphenyl-trichloroethane (DDT), and polybrominated diphenyl esters are chemicals of major concern at sites throughout the country. Although a comparable national assessment has not been completed in Canada, there is abundant evidence that freshwater sediments throughout the county have been contaminated due to human activities (MacDonald *et al.* 1993; Smith *et al.* 1996; Zarull *et al.* 2001). These results emphasize the extent to which sediments have been contaminated by human activities and underscore the need for reliable information to support the management of contaminated sediments.

Concerns regarding the effects of contaminated sediments on beneficial water uses have prompted action under a number of federal, state, and provincial programs. Importantly, investigations have been conducted throughout North America to assess the nature, extent, and severity of sediment contamination. Although these investigations often have a number of common elements, their objectives frequently differ depending on the regulatory program under which they are conducted. The following sections of this appendix provide descriptions of the types of assessments that are being conducted under various regulatory programs, including:

- State and Tribal Water Quality Standards and Monitoring programs;
- Total Maximum Daily Load (TMDL) program;
- National Pollutant Discharge Elimination System (NPDES) permitting program;
- Dredged Material Management program;
- Ocean Disposal program;
- Comprehensive Environmental Response, Compensation, and Liability Act (i.e., CERCLA; Superfund) program;
- British Columbia Contaminated Sites program;
- Resource Conservation and Recovery Act (RCRA) program;
- Federal Insecticide, Rodenticide and Fungicide Act (FIFRA) program;
- Toxic Substances Control Act (TSCA) program;
- Damage Assessment and Restoration program; and,
- Status and Trends Monitoring programs.

A description of the objectives of each of these types of programs is presented in the following sections of this document. This information on the objectives of each regulatory program and on the types of sediment quality assessments that are being conducted was obtained primarily from USEPA (1993; 1998a; 2000a) and ASTM (2001a). A description of the Contaminated Sediment Management Strategy that has been developed by USEPA (which has the primary authority for managing contaminated sediments in the United States) to guide sediment management initiatives is provided in Appendix 2 of Volume II (USEPA 1998a).

A1.1 State and Tribal Water Quality Standards and Monitoring Programs

The primary objective of state and tribal water quality standards and monitoring programs is to protect and maintain designated uses of aquatic ecosystems. USEPA recommends that

States and Tribes use their narrative water quality criteria (e.g., "no toxics in toxic amounts") to protect sediment quality, as necessary to support the protection and maintenance of designated uses (USEPA 2000c). Attainment of such criteria can be evaluated using the results of whole-sediment toxicity tests (or benthic community assessments, if desired) as the primary indicator for identifying waters that are not attaining the applicable water quality standards with respect to sediment quality. If testing indicates that a sediment causes toxicity, sediment chemistry data, SQGs, TIE procedures, and/or and spiked-sediment toxicity tests can be used to help identify chemicals that are contributing to the observed toxicity (see Chapter 3 of Volume III). Numerical SQGs can also be used to help determine pollutant reductions necessary to meet water quality standards. Where toxicity testing has not already been performed, available SQGs can be used to help prioritize water bodies for such testing. As well, SQGs can act as benchmarks for monitoring progress toward meeting water quality standards.

A1.2 Total Maximum Daily Load Program

The objective of the TMDL program is to identify the total maximum daily loads of each contaminant which, if not exceeded, will ensure that the ambient water quality criteria are met in the receiving water bodies. Such calculations are intended to enable water quality managers to allocate the total maximum daily load of various chemical substances among various pollution sources, including natural background sources, non-point sources, and point source discharges. Section 303(d) of the CWA provides that States and authorized Tribes are to establish TMDLs at levels necessary to implement the applicable water quality standards. Every two years, the states are required to:

- Identify waters that do not meet water quality standards and still require TMDLs;
- Rank waters in priority order; and,
- Develop TMDLs according to this ranking.

The TMDLs specify the particular source reductions necessary to attain and maintain water quality standards. In this way, TMDLs represent important tools for managing water quality conditions because they facilitate allocation of assimilative capacity among the multiple sources of contaminants that are present within a receiving water body.

Information to support the development of TMDLs that consider sediment quality conditions may include the use of whole-sediment toxicity tests, benthic community surveys, sediment chemistry data, and SQGs (USEPA 1998a; Volume III). Using the approach recommended by USEPA, states or tribes would utilize whole-sediment toxicity tests and other appropriate tools to interpret their narrative criteria with respect to sediment toxicity (i.e., in the absence of applicable state or tribal numerical sediment quality standards; USEPA 2000c). If the applicable state or tribal water quality standard is not attained for a water body, then the water body would be listed under Section 303(d) of the CWA and a TMDL would need to be developed. Numerical SQGs, along with TIEs, whole-sediment toxicity tests, or spiked-sediment toxicity tests, can be used to help identify the substances that are causing or substantially contributing to sediment toxicity. These substances are then targeted for the development of TMDLs. Numerical SQGs provide a basis for determining the magnitude of the reductions in contaminant concentrations needed to mitigate sediment toxicity. Sediment quality modeling can be used in development of TMDLs that address sediment toxicity. There are a number of sediment models available (Ingersoll *et al.* 1997), but sediment modeling is a relatively resource-intensive tasks and the results must be field validated to confirm their reliability. Historic sediment chemistry and contaminant loading data can also be used to estimate the loading reductions needed to achieve the narrative criteria with respect to sediment toxicity. Follow-up monitoring should include sediment chemistry analyses to verify that numeric targets are being met, as well as whole-sediment toxicity tests to verify that the sediments are not toxic.

A1.3 National Pollutant Discharge and Elimination System Permitting Program

The objective of the NPDES permitting program is to establish water quality-based effluent discharge limits to protect receiving waters from contamination by point sources (USEPA 2000c). NPDES permits represent the primary tools for ensuring that point source effluent discharges do not compromise our ability to meet applicable water quality standards. Since 1994a, sediment contamination has been considered in the selection of new industrial categories of chemicals for the development of effluent quality criteria. However, most NPDES permits do not contain discharge limits that are specifically developed to protect sediment quality. Some of the information that can be used to support decision making on NPDES permits relative to sediment quality conditions includes whole-sediment toxicity tests, TIE procedures, bioaccumulation tests, sediment chemistry data, and SQGs (USEPA 1998a; Volume III).

Regulations promulgated by USEPA require permitting authorities to develop water quality-based effluent limits under the NPDES permitting program, if a discharge is shown, or has reasonable potential, to cause or contribute to an exceedance of applicable water quality standards, including narrative criteria. Where the exceedance is due to sediment contamination, the permit limits would then be based on sediment quality protection. If sediment downstream of a discharge exhibits toxicity and the causative toxicant appears in the effluent, the permitting authority or permittee should perform a more detailed analysis (i.e., modeling) to confirm and quantify the impacts of the discharge. If modeling indicates that the discharge contributes to the existing sediment contamination, appropriate effluent limits should be developed. There may be cases where ambient sediment does not yet exhibit toxicity, but a regulatory authority may want to ensure that additional loadings from a point source will not create a sediment toxicity problem. In situations where predictive modeling indicates that a discharge would result in harmful levels of sediment contamination, the regulatory authority could decide that there is sufficient evidence that the additional loadings would contribute to sediment contamination. Sediment quality guidelines could then be used, in conjunction with applicable modeling activities, to establish effluent limits that would help meet applicable water quality standards (USEPA 2000c). Importantly, the results of the TMDL process will also provide essential information to support NPDES permitting.

A1.4 Dredged Material Management Program

The objective of the Dredged Material Management program is to evaluate the potential environmental effects associated with the disposal of dredged material in open water and in confined disposal sites, as well as the possibility of using dredged material for beneficial purposes, such as beach enrichment (USEPA 1992). Decisions on the management of dredged materials are primarily supported by information on the toxicity of whole sediments and elutriates in short-term tests (i.e., 4- to 10-day exposures), and on the bioaccumulation of sediment-associated contaminants (USEPA and USACE 1998a). As such, the dredged material management program, which is authorized under Section 103 of the Marine Protection, Research, and Sanctuaries Act (MPRSA) and Section 404 of the CWA, relies heavily on the results of effects-based testing to evaluate the suitability of dredged material for disposal. Although there is no requirement for utilizing sediment chemistry data in the evaluation of dredged material, such data could form part of the information base evaluated to determine whether further assessment of contaminated sediment is warranted (USEPA and USACE 1998a). For example, in situations where only sediment chemistry data are available (i.e., no data exists on sediment toxicity), and such data indicate that contaminant concentrations exceed SQGs (Chapter 2 and 3 of Volume III), then there is "reason to believe" that further biological testing is necessary to evaluate the suitability of dredged materials for open water disposal. However, a lack of exceedances of SQGs would not provide sufficient justification for concluding that no further testing is warranted (i.e., due to the potential presence of unmeasured substances or due to the lack of applicable SQGs).

In 1992, USEPA and USACE published a guidance document entitled, ***Evaluating Environmental Effects of Dredged Material Management Alternatives - A Technical Framework*** (USEPA 2000c). The document discusses the regulatory requirements of applicable statutes, the equipment and techniques employed in dredging and disposal, and the general framework in which disposal alternatives are evaluated. In addition, guidance is provided for conducting more detailed assessments for evaluating open water and confined disposal options, as well as beneficial use alternatives. The analysis of each of these major alternatives includes an evaluation of disposal site characteristics, physical effects of material disposal, site capacity and suitability, and contaminant pathways of concern. The management actions and control measures that are needed to contain sediment-associated contaminants are also identified during this type of analysis. See Figures A1.1 to A1.4 for an overview of the tiered approach for evaluating the potential impacts of aquatic disposal of dredged material.

A1.5 Ocean Disposal Program

Like the United States Dredged Material Management program, the Canadian Ocean Disposal program is intended to evaluate the suitability of dredged materials for open water disposal. A tiered testing approach has been developed to facilitate cost-effective assessments of dredged materials. In the first tier of the assessment, samples of the materials to be dredged are obtained and analyzed for a suite of priority substances, including but not necessarily limited to metals, PAH, and PCBs. The measured concentrations of these variables are then compared to numerical SQGs [i.e., threshold effect levels (TELs) and probable effect levels (PELs); CCME 1999]. If the concentrations of all measured analytes are below the screening levels (TELs), then the material is considered to be unlikely to cause adverse effects. Such material may be disposed at approved open water disposal sites. In contrast, dredged materials are considered to be unsuitable for open water disposal if the concentrations of one or more analytes exceed the rejection levels (PELs). If the concentrations of one or more substances fall between the screening and rejection levels, then further investigations are required to assess the suitability of the material for open water disposal.

In the second tier of the assessment, a suite of bioassessment tools is used to further evaluate the effects associated with exposure to the material under investigation. The suite of bioassessment tools used in this evaluation includes:

- 10-day whole-sediment toxicity test with amphipods, in which survival is the endpoint measured;
- Short-term pore water toxicity with echinoderms, in which fertilization is the endpoint measured;
- Short-term whole-sediment toxicity test with the bacterium, *Vibrio fisheri* (i.e., Microtox), in which bioluminescence is the endpoint measured;
- 20-day whole-sediment toxicity test with polychaetes, in which growth is the endpoint measured; and,
- 28-day whole-sediment bioaccumulation test with clams, in which tissue residue levels is the endpoint measured.

Decisions regarding the suitability of a material for open water disposal are then made based on the results of these tests. If all tests pass, the material is considered to be rapidly rendered harmless (RRH) and, hence, suitable for open water disposal. If the material is found to be not toxic to amphipods but one of the other tests fail, then disposal is allowed only with special handling techniques. However, the material is considered unsuitable for ocean disposal if it is found to be toxic to amphipods or if two of the tests fail.

A1.6 Comprehensive Environmental Response, Compensation, and Liability Act Program

The objective the CERCLA program, which is also known as Superfund, was established to facilitate clean up of hazardous waste sites to protect human health, welfare, and the environment (USEPA 2000c). The Superfund program identifies, investigates, and remediates sites contaminated with hazardous substances. The Superfund process provides a tiered process for evaluating sites relative to their inclusion on the National Priorities List (NPL). The process is not designed specifically for sediments, but rather provides a basis for assessing risks to ecological receptors and human health associated with exposure to contamination at a site via all exposure routes. The types of information used to support the assessment and management of contaminated sediments at such sites include the results of whole-sediment toxicity tests, benthic community surveys, and bioaccumulation tests (Chapter 3, 4 and 5 of Volume III). Sediment chemistry data have also been used in conjunction with SQGs to assess risks to ecological receptors associated with exposure to contaminated sediments (Chapter 2 of Volume III). Information on the levels of contaminants in sediments and tissues, in conjunction with appropriate benchmarks, have also been used to assess risks to wildlife and human health. The results of sediment assessments are used both in site assessment and in remedy selection (USEPA 1993).

In the Superfund program, SQGs are often used by investigators during the screening level ecological risk assessment, which is conducted as part of the Remedial Investigation/Feasibility Study (USEPA 2000c). In this application, SQGs have been used to screen out contaminants or portion of a site from further consideration. Substances that occur at concentrations below SQGs would generally not be carried through as chemicals of potential concern (COPCs) into the baseline risk assessment. However, substances that occur at concentrations above the SQGs would warrant further investigation. While SQGs are primarily used for screening purposes, they can also be used to support the establishment of cleanup levels at sites with contaminated sediments (USEPA 2000d; MacDonald *et al.* 2001).

A1.7 British Columbia Contaminated Sites Program

The objective of the component of the British Columbia Contaminated Sites program is to manage contaminated sites to protect human health and the environment. A tiered framework has been established to support the assessment and management of contaminated sediments in the province. Identification of the site as potentially containing contaminated sediments represents the first tier in the framework. There are a number of property management activities that can trigger the site assessment process; however, the presence of Schedule 2 (of the Waste Management Act; WMA) activities in the upland portion of the site is the most common trigger (see Table 3.1 of Volume I). In such cases, a site profile is completed to provide the responsible agency with sufficient information to determine if the site is potentially a contaminated site, including the potential for sediment contamination.

A preliminary site investigation (PSI) is required at any site that is suspected of having contaminated sediments (Chapter 3 of Volume II). The objective of the PSI is to evaluate the nature, degree, and extent of sediment contamination at the site. As such, a sampling program is designed and implemented to obtain sufficient sediment samples to characterize the concentrations and distributions of contaminants at the site. The measured concentrations of each analyte are then compared to numerical SQGs to determine if the site is legally contaminated (i.e., if one of more substances exceed the SQGs in more that 10% of the samples). Further investigation or remediation is required at sites that are found to have contaminated sediments.

The additional investigations (i.e., detailed site investigation; DSI) that are conducted at the site are intended to assess the risks posed by contaminated sites to human health and the environment. For sites that contain toxic substances that partition into sediments (e.g., metals PAHs), such investigations are designed to assess toxicity to sediment-dwelling organisms. Although short-term toxicity tests have been used extensively to date, longerterm toxicity tests (e.g., 28-day toxicity tests with the amphipod, *Hyalella azteca*) will be required in the future. More comprehensive investigations are required at sites that contain both toxic and bioaccumulative substances (e.g., PCBs).

The results of the DSI are intended to provide the information needed to determine if the site is legally contaminated, as defined under the WMA. Remedial action is usually required at sites that are determined to be legally contaminated. Numerical sediment quality standards (SQSs) provide the benchmark for establishing clean-up targets and evaluating the efficacy of remedial measures. Numerical SQSs can be established using either of two approaches including the criteria-based approach and the risk-based approach. Using the criteria-based approach, the numerical SQG can be adopted directly as SQSs or site-specific SQS may be derived using approved procedures. Alternatively, the risk-based approach may be applied to establish tolerable risk levels at the site. In this case, clean-up levels are often established by determining the level of contamination that roughly corresponds to an LC_{20} or an EC_{50} for appropriately selected receptors and/or endpoints.

A1.8 Resource Conservation and Recovery Act Corrective Action Program

The objective of the RCRA program is to clean up hazardous waste sites to protect human health, welfare, and the environment (USEPA 2000c). USEPA has authority to assess whether releases from a hazardous waste treatment, storage, or disposal facility have contaminated sediments and require corrective action (USEPA 1998a). Under this program, sediments may be identified as toxic using the RCRA toxicity characterization leaching process (USEPA 1993). Under this process, concentrations of various chemicals in a leachate are compared to concentrations established to protect human health and the environment. The information used to support decision making relative to contaminated sediments is similar to that described above for Superfund (Section A1.6; USEPA 1993).

A1.9 Federal Insecticide, Rodenticide and Fungicide Act Program

The objective of the FIFRA program is to evaluate the effects on non-target organisms of new and existing chemicals registered as pesticides (USEPA 2000c). While the program considers all potential exposure routes, contaminated sediments represent an important route of exposure for substances that partition into this medium. For these types of chemicals, the results of spiked-sediment toxicity tests provide the requisite information for assessing the toxicity and bioavailability of contaminants in sediment (USEPA 2000a; ASTM 2001a). Such dose-response relationships provide a basis for determining how varying application rates and uses of chemicals are likely to adversely affect exposed species. Information on the fate and transport of potential sediment-associated contaminants is also collected under this program to support decisions on the registration of pesticides (USEPA 1993).

A1.10 Toxic Substances Control Act Program

The objective of the TSCA program is to reduce the risks associated with possible releases of existing and new chemicals that are manufactured, distributed or disposed of in the United States (USEPA 2000c). Under TSCA, the USEPA has the authority to regulate new and existing chemicals that have the potential to contaminate sediments, if the potential risks to human health or the environment are judged to be unreasonable. USEPA is developing a program to assess the environmental fate and effects of toxic chemicals that could potentially contaminate sediments into the routine chemical review processes that are conducted under TSCA (USEPA 1998a). In this application, the results of spiked-sediment toxicity and bioaccumulation tests are used to determine the bioavailability of contaminants in sediment (USEPA 2000a; ASTM 2001a). Additionally, information is collected on the fate and transportation of potential sediment-associated contaminants (USEPA 1993). Together, these data are used to support decisions on the regulation of new and existing chemicals that could be released into the environment.

A1.11 Damage Assessment and Restoration Program

Pursuant to the CERCLA, OPA, and CWA, federal and state officials act as trustees for natural resources on behalf of the public. When acting in this capacity, such officials are authorized to conduct natural resource damage assessments (NRDAs) following the discharge of oil or the release of hazardous substances into the environment. The purpose of such assessments is to determine if natural resources have been injured by discharges of oil or releases of other hazardous substances, to quantify any injuries that have occurred to water or biological resources, and to determine the damages that are associated with those injuries (including the costs associated with restoration of injured resources and the monetary value of natural resource services that were lost prior to restoration).

Two sets of regulations have been promulgated to guide natural resource trustees in the assessment of injuries and damages (Weiss *et al.* 1997). In 1987, the Department of the Interior (DOI) issued regulations for conducting damage assessments following the discharge of oil or the release of hazardous substances under the authority of the CERCLA and CWA. Subsequently (1996), the National Oceanic and Atmospheric Administration (NOAA) issued regulations for the assessment of damages resulting from a discharge or a substantial threat of discharge of oil. Where both oil and other hazardous substances have been released, the DOI regulations are considered to take precedence, although the NOAA regulations may also provide useful guidance.

The NRDA process consists of two main steps, including a pre-assessment screen and a damage assessment. In the pre-assessment screen, readily available data and information are reviewed to determine if the trustees have a reasonable probability of making a successful damage claim. If the results of the pre-assessment screen indicate that a damage assessment is warranted, then an assessment plan is developed to guide the design and implementation of the assessment, and to communicate the proposed assessment methods to potentially responsible parties and to the public. Under the DOI regulations, two types of assessments may be conducted, including Type A and Type B assessments. The Type A assessment involves a simplified process that relies only minimally on field observations and applies to minor, short duration releases of oil and/or other hazardous substances. The Type B assessment comprises a more comprehensive set of studies and analyses, and applies to major, long duration releases of oil and/or other hazardous substances.

The DOI is currently developing a revision to the Type B NRDA rule which more directly addresses sediment injury. In the context of NRDA, sediment injury has been defined as the presence of conditions that have injured or are sufficient to injure sediment-dwelling organisms, fish, or wildlife (MacDonald and Ingersoll 2000). MacDonald and Ingersoll (2000) conducted an assessment of sediment injury in the Grand Calumet River and Indiana Harbor located in southern Lake Michigan. Information on a total of nine indicators of sediment quality conditions was collated, evaluated, compiled from the assessment area. These indicators included the chemical composition of sediment, pore water, and tissues, the toxicity of whole sediments, pore water, and elutriates to aquatic organisms, the status of benthic invertebrate and fish communities, and fish health. The data on each of these indicators were compared to regionally-relevant benchmarks to determine if sediments, sediment-dwelling organisms, and/or fish and wildlife resources in the assessment area had been injured due to discharges of oil or releases of other hazardous substances. The same data and benchmarks were also used to establish the areal extent of sediment injury.

A1.12 Status and Trends Monitoring Programs

There are a number of programs designed to evaluate the nature, severity, and extent of sediment contamination on broad geographic or temporal scales. These programs include the USEPA Environmental Monitoring and Assessment Program (EMAP; USEPA 1997b), the USEPA National Sediment Quality Survey (NSQS; USEPA 1997a), the NOAA National Status and Trends Program (NSTP; Long and Morgan 1991), and the United States Geological Survey (USGS) National Water Quality Assessment (NAWQA) Program.

The EMAP program was established to conduct research to develop the tools necessary to monitor and assess the status and trends of national ecological resources. The goal of EMAP is to develop the scientific understanding needed to translate environmental monitoring data from multiple spatial and temporal scales into assessments of ecological conditions and forecasts of the future risks to the sustainability of natural resources. The objectives of EMAP are to advance the science of ecological monitoring and ecological risk assessment, and to guide national monitoring with improved scientific understanding of ecosystem integrity and dynamics. Indicators have been developed for use in monitoring the condition of ecological resources, and investigating multi-tier designs that address the acquisition and analysis of multi-scale data including aggregation across tiers and natural resources. The sediment assessment portion of the EMAP program has included whole-sediment chemistry for major contaminants (organic and inorganic), whole-sediment toxicity testing (primarily 10-day toxicity tests), and benthic community surveys.

The NSQS was conducted to provide Congress with a comprehensive evaluation of sediment quality conditions in the United States. More specifically, the NSQS was designed to:

- Obtain information on the extent and severity of the problem of contaminated sediments nationwide;
- Identify areas that may be contaminated and need further assessment; and,
- Identify areas that may be associated with adverse effects to human health or the environment.

To support the fulfillment of these objectives, the NSQS developed a database describing the levels of chemical contaminants in river, lake, ocean, and estuary sediments. Information from over 21,000 sampling stations in the United States were compiled to evaluate sediment chemistry, chemical residues in edible tissue of aquatic organisms, and sediment toxicity. The information contained in this database were then utilized to conduct a screening level assessment of the potential for adverse effects on human and environmental health. This database is currently being updated with recently-collected information to support the second report to Congress on sediment quality conditions in the United States.

The NSTP is designed to monitor spatial and temporal trends of chemical contamination and biological responses to that contamination. Temporal trends are being monitored through the Mussel Watch project, in which mussels and oysters are collected annually at about 200 sites throughout coastal and estuarine areas of the United States. Spatial trends have been described on a national scale from chemical concentrations measured in surface sediments collected from 240 sites distributed throughout the coastal and estuarine United States under both the Mussel Watch and Benthic Surveillance Projects. In addition, the Benthic Surveillance Project has measured chemical concentrations in fish livers and performed histological analyses of fish for evidence of biological responses to chemical contamination. The sediment assessment portion of the NSTP is primarily focused on the collection and interpretation of data on whole-sediment chemistry for major COCs (organic and inorganic chemicals), whole-sediment toxicity tests, pore water toxicity tests, toxicity tests with organic extracts of sediments, and benthic community surveys.

The NAWQA program was designed to describe the status and trends in the quality of the Nation's ground- and surface-water resources and to provide an understanding of the natural and human factors that affect the quality of these resources. As part of the program, investigations are being conducted in 59 areas called "study units" located throughout the United States. These investigations are designed to provide a framework for national and regional water-quality assessment. Regional and national synthesis of information from study units will consist of comparative studies of specific water-quality issues using nationally consistent information. The sediment assessment portion of NAWQA is based primarily on whole-sediment chemistry for major COCs (organic and inorganic chemicals).

Appendix 2 USEPA Contaminated Sediment Management Strategy

The USEPA has primary authority under a variety of statutes to manage contaminated sediments in the United States (Table A2.1). The USEPA Contaminated Sediment Management Strategy (USEPA 1998a) established the following four goals for managing contaminated sediments, including:

- To prevent further contamination of sediments that may cause unacceptable ecological or human health risks;
- When practical, to clean up existing sediment contamination that adversely affects the Nation's waterbodies or their uses, or that causes other significant effects on human health or the environment;
- To ensure that sediment dredging and the disposal of dredged material continue to be managed in an environmentally-sound manner; and,
- To develop and consistently apply methodologies for analyzing contaminated sediments.

The USEPA plans to employ its pollution prevention and source control programs to address the first goal. To accomplish the second goal, USEPA plans to use a range of risk management alternatives to reduce the volume and effects of existing contaminated sediments, including natural recovery, *in-situ* containment, and contaminated sediment removal. Finally, USEPA is developing tools for use in pollution prevention, source control, remediation, and dredged material management to meet all of these goals. These tools include national inventories of sediment quality and environmental releases of contaminants, numerical assessment guidelines to evaluate contaminant concentrations, and standardized methods for conducting toxicity tests to evaluate the bioaccumulation and toxicity of sediment samples (USEPA 1997c; 2000a).

The Clean Water Act is the single most important law dealing with quality of surface waters in the United States, with the Comprehensive Environmental Response, Compensation and

Sanctuaries Act, the Marine Protection and Research Act, and the Oil Pollution Act playing complimentary roles. The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters (Clean Water Act, Section 101). Federal and state monitoring programs have traditionally focused on evaluating water quality issues associated with point source discharges. The results of the National Sediment Quality Survey, Volume I of the first biennial report to Congress on sediment quality in the United States, indicated that this focus needs to be expanded to consider the impacts associated with contaminated sediments (USEPA 1997c). The extent and severity of sediment contamination in the United States, as documented in the National Sediment Inventory and in various contaminated site assessments, emphasized the need for better tools for reducing and preventing sediment contamination (USEPA 1997c). Such tools include whole-sediment toxicity tests, benthic community analyses, and chemically-based SQGs. Sediment toxicity tests directly measure toxicity to test organisms under laboratory conditions and are especially valuable because the results of these studies can be used to evaluate the interactive effects of chemical mixtures (USEPA 2000b). Benthic community analyses are also useful because they provide information that is directly relevant for assessing the biological integrity of the system under investigation. Numeric SQGs represent important assessment tools because they provide a basis for identifying the substances that are causing or substantially contributing to toxicity. Numeric SQGs can also provide substance-specific targets for protecting and restoring sediment quality conditions (USEPA 2000b).

The Office of Water, the Office of Prevention, Pesticides, and Toxic Substances, the Office of Solid Waste, and the Office of Emergency and Remedial Response are all committed to the principle of consistent tiered testing of contaminated sediments, as described in the Contaminated Sediment Management Strategy (USEPA 1998a). Tiered testing refers to a structured, hierarchical procedure for satisfying data needs relative to decision-making that consists of a series of tiers, or levels, of investigative intensity. Typically, increasing levels in a tiered testing framework involve increased information generation and decreased uncertainty (USEPA 1998a). Consistent tiered testing is desirable because it ensures that all USEPA programs will use similar methods to generate data (hence assuring data comparability) and to assess risks to ecological receptors and human health. It will also provide the basis for uniform cross-program decision-making within the USEPA. Each program, however, retains the flexibility of deciding whether identified risks would trigger regulatory actions.

Each USEPA program office intends to develop guidance for interpreting the tests conducted within the tiered framework and to explain how the information generated within each tier would be used to trigger regulatory action. Depending on statutory and regulatory requirements, the program specific guidance will describe how decisions are to be made, potentially involving a weight of evidence approach, a pass-fail approach, or comparisons to reference sites. The following two approaches are currently being used by USEPA: (1) the Office of Water-U.S. Army Corps of Engineers dredged material testing framework; and, (2) the OPPTS ecological risk assessment tiered testing framework. USEPA and USACE (1998b) describes the dredged material testing framework, while Smrchek and Zeeman (1998) summarizes the OPPTS testing framework. A tiered testing framework has not yet been selected for Agency-wide use, but some of the components have been identified. These components include toxicity tests, bioaccumulation tests, SQGs, and other tools for evaluating the potential for ecological effects (such as benthic community structure, colonization rates, and *in situ* testing within mesocosms; USEPA 2000a).

Appendix 3 Additional Considerations for Designing Sediment Quality Sampling Programs

A3.0 Introduction

To be effective, a sediment quality sampling program must be designed to fulfill the specific objectives that have been established for the assessment. The types and objectives of freshwater sediment quality assessments were discussed in Appendix 1 of Volume II. In addition, guidance on the design and implementation of preliminary and detailed site investigations was provided in Chapter 3 and Chapter 4 of Volume II, respectively, of this guidance manual. Furthermore, the key elements of sampling and analysis plans for assessing contaminated sediments were identified in Chapter 5 of Volume II. The supplemental guidance that is offered in this appendix is intended to provide additional information on the design of sediment quality sampling programs, including the selection of control and reference sediments. This information was obtained primarily from USEPA (2001), ASTM (2001c) and CDM (2000).

A3.1 Selection of Sampling Stations

The study area (or site) refers to the body of water that contains the sampling station(s) to be evaluated, as well as adjacent areas (land or water) that might influence the conditions of the sampling station. The size and characteristics of the study area will influence the sampling design and station positioning methods. The boundaries of the study area need to be defined using a hydrographic chart or topographic map.

The selection of an appropriate sampling design is one of the most critical steps designing the study. The design will be a product of the general study objectives. Station location and sampling methods will necessarily follow from the study design. Ultimately, a study design should control extraneous sources error to the extent possible so that data are directly applicable for addressing the project objectives.

Most projects do not have the resources to fully characterize the spatial or temporal variability of sediment quality conditions. To address the constraints imposed by resource limitations, sampling can be restricted to an index period when biological measures are expected to show the greatest response to pollution stress and within-season variability is the lowest (Holland 1985; Barbour *et al.* 1999). This type of sampling can be also be advantageous for characterizing benthic invertebrate and fish community structure in the field. In addition, this approach is useful if sediment contamination is related to high flow events (USEPA 2001). Alternatively, investigations can focus on measurement endpoints that exhibit less seasonal variability (e.g., sediment toxicity).

There are a number of options for selecting sampling stations; however, most of these options fall into two major categories of design, including random sampling and targeted (or biased) sampling. USEPA (2001) presents a thorough discussion of sampling design issues and detailed information on the various sampling designs, including the following recommendations regarding sampling design:

- Historical data and the locations of sediment deposition zones should be considered when selecting sampling stations;
- A systematic sampling strategy may be most appropriate if the objective of the program is to identify areas of toxic or contaminated sediments on a quantitative spatial or temporal basis.
- A targeted station location design may be most appropriate if the objective of the program is to evaluate the extent of sediment contamination originating from a specific source or tributary.
- Stratified sampling should be used where historical, sediment-mapping data are available and there are well-defined zones of different sediment types or adjacent land uses.
- A probability-based random sampling design may be most appropriate for watershed or regional assessment programs.

In systematic random sampling, the first sampling location is chosen randomly and all subsequent stations are placed at regular intervals (e.g., 50 meters apart) throughout the study area. Depending on the types of analyses desired, such sampling can become expensive unless the study area is relatively small or the density of stations is relatively low. Systematic sampling can be effective for detecting previously unknown "hot spots" in the study area.

Targeted sampling of sediments is appropriate for situations in which any of the following apply: (1) relatively small-scale features or conditions are under investigation; (2) small numbers of samples (e.g., fewer than 20 observations) will be evaluated; (3) there is reliable historical and physical knowledge about the feature or condition under investigation; (4) the objective of the investigation is to screen an area(s) for contamination at levels of concern; or (5) schedule or budget limitations preclude the possibility of implementing a statistical design (USEPA 2001).

Targeted sampling designs can often be quickly implemented at a relatively low cost. As such, this type of sampling can meet schedule constraints that cannot be met by implementing a more rigorous statistical design. In many situations, targeted sampling offers an additional important benefit of providing an appropriate level-of-effort for meeting objectives of the study within a limited budget. Targeted sampling does not allow the level of uncertainty in the field sampling to be accurately quantified. In addition, targeted sampling limits the inferences that can be made to the units actually analyzed and the extrapolation from those units to the overall population from which the units were collected.

In stratified designs, the selection probabilities may differ among strata. Stratified random sampling consists of dividing the target population into non-overlapping parts or subregions (e.g., watersheds), which are termed strata, to obtain a better estimate of the mean or total for the entire population. The information required to delineate the strata and estimate sampling frequency needs to be known before sampling. This information is typically obtained from historic data or by conducting a reconnaissance survey. Sampling locations are randomly selected from within each of the strata.

A related design is multistage random sampling, in which large subareas within the study area are first selected (usually on the basis of professional knowledge or previously collected information). Stations are then randomly located within each subarea to yield average or pooled estimates of the variables of interest. This type of sampling is especially useful for statistically comparing variables among specific parts of a study area.

Use of random sampling designs may miss relationships among variables, especially if there is a relationship between an explanatory and a response variable. As an example, estimation of contaminant concentrations nearby an outfall requires data from a number of sampling stations, including those located directly adjacent to the outfall and those that are located further from the outfall. A simple random sample of stations may not capture the entire range, because the high end of the gradient would likely be under-represented in the design.

Probability-based sampling designs avoid bias in the results of sampling by randomly assigning and selecting sampling locations. A probability design requires that all sampling units have a known probability of being selected. Stations can be selected on the basis of a random scheme or in a systematic way (e.g., sample every 10 meters along a randomly chosen transect). In simple random sampling, all sampling units have an equal probability of selection. This design is appropriate for estimating means and totals of environmental variables if the population is homogeneous. To apply simple random sampling, it is necessary to identify all potential sampling times or locations, then randomly select individual times and/or locations for sampling.

A3.2 Sample Size, Number of Samples, and Replicate Samples

Typical sediment volume requirements for each end use are summarized in USEPA and ASTM standard methods (e.g., ASTM 2001a; USEPA 2001; Table 5.3). The testing laboratory should be consulted to confirm the amount of sediment required for each toxicity test or chemical analysis. The number of samples to be collected usually results from a compromise between the ideal and the practical. The major practical constraints are the costs of analyses and logistics of sample collection. The collection of replicate samples within a sampling station can provide an estimate of the variability in analytical results due to sediment-heterogeneity and sampling error. Such analyses can strengthen comparisons among and between sampling stations. However, collection of replicate samples within a station will dramatically increase the cost of the assessment.

Before starting a sampling program, the type and number of analyses and tests needs to be determined and the required volume of sediment per sample needs to be established. When determining the required sample volumes, it is useful to know the general characteristics of the sediments being sampled. For example, if pore water analyses are to be conducted, the percent water of the sediment will influence the amount of water extracted. It is recommended that additional sediment (i.e., beyond the volume that is calculated to meet the needs of the various chemical analyses and toxicity tests) be collected at each station during the sampling program and stored in an appropriate way in the laboratory. In this way, it will be possible to retest samples that yield anomalous results or to provide sediment to other laboratories if samples are lost or broken during transport.

The number of samples collected is usually determined by the size of the sampling station, type and distribution of the contaminants being measured, heterogeneity of the sediment, concentrations of contaminants in the sediments, sample volume requirements, and desired level of statistical resolution. Accordingly, sample requirements needs to be determined on a case-by-case basis. The number of samples to be collected will ultimately be an outcome of the questions asked. For example, if one is interested in characterizing effects of a point source or a gradient (e.g., effects of certain tributaries or land uses on a lake or estuary), then many samples in a relatively small area may need to be collected and analyzed. If, however, one is interested in identifying "hot spots" or locations of high contamination within a watershed or large water body, relatively few samples at targeted locations may be appropriate. The number of samples to be collected usually results from a compromise between the ideal and the practical. The major practical constraints are the logistics of sample collection and the costs of analyses.

The objective of collecting replicate samples at each sampling station is to allow for quantitative statistical comparison within and among different stations. Separate subsamples from the same grab or core sample might be used to measure the variation within a sample but not necessarily within the station. The collection of separate samples within a sampling station can impart valuable information on the spatial distribution of contaminants at the station and on the heterogeneity of the sediments within the station. However, the collection of replicate samples at each station will dramatically increase the analytical chemical costs needed for the assessment. Approaches that can be used to determine the number of replicates required to achieve a minimum detectable difference at a specific confidence level and power are outlined in USEPA (2001). Traditionally, acceptable coefficients of variation vary from 10 to 35%, the power from 80 to 95%, the confidence level from 80 to 99%, and the minimum detectable relative difference from 5 to 40%.

Replicate samples collected from a sampling station can be kept separate and treated as true replicate samples, or they can be combined to generate a composite sample. A composite sample from a sampling station is treated as a single sample. Compositing of sediment samples within a habitat location might be desirable if resources prevent detail spatial characterization, if a large area is being sampled, or if split sampling is being conducted (e.g., comparisons of toxicity, bioaccumulation, and sediment chemistry; ASTM 2001a).

A3.3 Control and Reference Sediments

Sediment toxicity and bioaccumulation tests must include a control sediment (sometimes called a negative control) to support an assessment of test validity (i.e., acceptability). A control sediment is a sediment that is essentially free of contaminants and is used routinely to assess the acceptability of a test and is not necessarily collected near the site of concern (ASTM 2001a; USEPA 2000a). For example, control sediments for toxicity tests can be obtained from the locations that the test organisms were collected. Any contaminants in control sediment are thought to originate from the global spread of pollutants and do not reflect any substantial inputs from local or non-point sources. Comparing test sediments to control sediments provides a means of measuring the toxicity of a test sediment beyond inevitable background contamination and organism health. A control sediment provides a measure of test acceptability, evidence of test organism health, and a basis for interpreting data obtained from the test sediments. A reference sediment is collected near an area of concern and is used to assess sediment conditions exclusive of material(s) of interest. Testing a reference sediment provides a site-specific basis for evaluating toxicity. It is recommended by USEPA (2000a) and ASTM (2001a) that a laboratory demonstrate acceptable control responses of organisms in a minimum of five separate tests with the control sediment and proposed test conditions.

In general, the performance of test organisms in the negative control is used to judge the acceptability of a test, and either the negative control or reference sediment may be used to evaluate performance in the experimental treatments, depending on the purpose of the study. Any study in which organisms in the negative control do not meet performance criteria must be considered questionable because it suggests that adverse factors affected the response of test organisms (i.e., other than the variables of interest, sediment contamination; ASTM

2001a; USEPA 2000a). The key to avoiding this situation is to use only control sediments that have a demonstrated record of performance for the test procedure that will be employed. This includes testing of new collections from sediment sources that have previously provided suitable control sediment. It is recommended by USEPA (2000a) and ASTM (2001a) that a laboratory demonstrate acceptable control responses of organisms in a minimum of five separate tests with the control sediment and proposed test conditions.

Because of the uncertainties introduced by poor performance in the negative control, such studies should be repeated to ensure the accurate results are generated. However, the scope or sampling associated with some studies may make it difficult or impossible to repeat a study (unless extra sediment was collected during the sampling program). Some researchers have reported cases where performance in the negative control is poor, but performance criteria are met in a reference sediment included in the study design. In these cases, it might be reasonable to infer that other samples that show good performance are probably not toxic; however, any samples showing poor performance should not be judged to have shown toxicity, since it is unknown whether the adverse factors that caused poor control performance might have also caused poor performance in the test treatments.

A3.4 Evaluation of Data Quality

Evaluation of the quality of the data that are collected in sediment sampling and analysis programs represents an essential element of the overall sediment quality assessment process. In general, there are five primary indicators of the quality of physical, chemical, and biological data, including:

- Precision;
- Accuracy;
- Representativeness;
- Completeness; and
- Comparability.

The following descriptions of these data quality indicators was obtained from CDM (2000).

Precision - The precision of a measurement is an expression of mutual agreement among individual measurements of the same property taken under prescribed similar conditions. Precision is quantitative and most often expressed in terms of relative percent difference (RPD). The precision of laboratory analyses is usually assessed by comparing duplicate analytical results, where applicable. The RPD is calculated for each pair of applicable duplicate analyses using the following equation:

$$\text{Relative Percent Difference} = [(S \bullet D) \div (S + D) \div 2)] \times 100$$

where:

S = First sample value (original value); and
D = Second sample value (duplicate value).

Precision of reported results is a function of inherent field-related variability and/or laboratory analytical variability, depending on the type of QC samples that are submitted. Data may be evaluated for precision using the following types of samples (in order of priority): field duplicates, laboratory duplicates, laboratory control sample/laboratory control sample duplicates (LCS/LCSDs), or matrix spike/matrix spike duplicates (MS/MSDs).

The acceptable RPD limits for duplicate measurements are listed in USEPA Contract Laboratory Program, National Functional Guidelines for Inorganic Data Review (USEPA 1994b) and USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review (USEPA 1999b).

Accuracy - Accuracy is the degree of agreement of a measurement with an accepted reference or true value and is a measure of the bias in a system. Accuracy is quantitative and usually expressed as the percent recovery (%R) of a sample result. Percent R is calculated as follows:

$$\text{Percent Recovery} = [SSR - (SR \div SA)] \times 100$$

where:

SSR = Spiked Sample Result
SR = Sample Result
SA = Spike Added

Ideally, the reported concentration should equal the actual concentration present in the sample. Data may be evaluated for accuracy using (in order of priority) certified reference materials, LCS/LCSDs, MS/MSDs, and/or surrogates. The acceptable %R limits are presented in USEPA National Functional Guidelines for Inorganic Data Review (USEPA 1994b) and USEPA National Functional Guidelines for Organic Data Review (USEPA 1999b). It should be noted that no procedures are currently available to evaluate the accuracy of toxicity tests.

Representativeness - Representativeness expresses the degree to which sample data accurately and precisely represent the characteristic being measured, parameter variations at a sampling point, and/or an environmental condition. Representativeness is a qualitative and quantitative parameter that is most concerned with the proper sampling design and the absence of cross-contamination of samples. Acceptable representativeness is achieved through:

- Careful, informed selection of sampling sites;
- Selection of testing parameters and methods that adequately define and characterize the extent of possible contamination and meet the required parameter reporting limits;
- Proper gathering and handling of samples to avoid interferences and prevent contamination and loss; and,
- Collection of a sufficient number of samples to allow characterization.

Representativeness is assessed qualitatively by reviewing the sampling and analytical procedures and quantitatively by reviewing the results of analyses of blank samples. If an analyte is detected in a method, preparation, or rinsate blank, any associated positive result less than five times (10 times for common laboratory contaminants) may be considered a false positive. Holding times are also evaluated to determine if analytical results are representative of sample concentrations.

Completeness - Completeness is a measure of the amount of usable data obtained from a measurement system compared to the amount that was expected to be obtained under correct normal conditions. Usability is determined by evaluating the PARCC parameters excluding completeness. Those data that are validated, evaluated and are not considered estimated, or are qualified as estimated or non-detect are all considered to be usable. Rejected data are not considered usable. Completeness is calculated using the following equation:

$$\text{Percent Completeness} = (DO \div DP) \times 100$$

where:

DO = Data Obtained and usable.
DP = Data Planned to be obtained.

A completeness goal of 90 percent is often applied to sediment quality assessments.

Comparability - Comparability is a qualitative parameter. Consistency in the acquisition, handling, and analysis of samples is necessary for comparing results. Application of standard methods and appropriate quality control procedures are the primary means of assuring comparability of results with other analyses performed in a similar manner.

Tables

Table 2.1. Examples of chemical contaminants that should be measured on a site-specific basis (from WDOE 1995).

Chemical Contaminant	Reason for Suspected Presence in Sediments
Ammonia	* Associated with fish processing plants and aquaculture
Other potentially toxic metals (e.g., antimony, beryllium, nickel)	* Associated with mining wastes and metal plating operations
Organotin complexes (especially tributyltin)	* Used historically in antifouling paint and, therefore, potentially associated with shipyards and marinas
Pesticides, herbicides	* companies
Petroleum compounds (e.g., benzene, toluene, ethylbenzene, xylene)	* gas stations
Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs)	* Associated with the presence of polychlorinated biphenyls and pentachloro-phenol and with pulp and paper mills using chlorination
Guaiacols and resin acids	* Associated with pulp and paper mills and other wood products operations
Volatile organic compounds (e.g., trichloroethene, tetrachloroethene)	* Used as solvents and in chemical manufacturing operations
Radioactive substances	* Associated with nuclear power plants, nuclear processing plants, medical wastes, and military installations

Note: the substances identified in this table should be measured when there is reason to suspect that they could be present in sediments. Measurement of these substances is in addition to the standard suite of analytes that should be measured at all sites with contaminated sediments, including PCBs, PAHs, and priority heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc).

Table 4.1. A matrix of dat:
(from Krantzberg *et al.* 2000).

Use Impairment	Assessment Element	Data Interpretation Tools	Sample References
Restriction on fish and wildlife consumption	Bioaccumulation	Equilibrium partitioning, comparison to guidelines	USEPA 1989; Beltran and Richardson 1992
Degradation of fish and wildlife populations	Community structure, bioaccumulation	Food web model, weight of evidence	USEPA 1989; Beltran and Richardson 1992
Fish tumors or other deformities	Bioaccumulation, chemistry	Reference frequencies	Baumann 1992
Bird or animals deformitites or reproduction problems	Bioaccumulation, community structure	Food web model, comparison to reference conditions, weight of evidence	Jaagumagi and Persaud 1996
Degradation of benthos	Community structure, toxicity (bioassays)	Comparison to reference conditions	Jaagmagi and Persaud 1996; Reynoldson *et al.* 1997
Restrictions on dredging activities (no open water disposal)	Chemistry, toxicity (bioassays), stability*	Comparison to guidelines and/or reference conditions	Persaud *et al.* 1993; USEPA 1998c
Eutrophic or undesirable algae	Chemistry, stability	Modeling	PDEP 1998
Degradation of aesthetics	Chemistry, stability	Comparison to reference conditions	Heidtke and Tauriainen 1996
Added costs to agriculture or industry (to prevent or avoid contaminated water)	Chemistry, stability	Comparison to reference conditions	OMOE and MDNR 1991

Table 4.1. A matrix of dat
(from Krantzberg *et al.* 2000).

Use Impairment	**Assessment Element**	**Data Interpretation Tools**	**Sample References**
Dregraded phytoplankton and zooplankton populations	Bioaccumulation, chemistry, stability	Comparison to reference conditions, target nutrient loads	Bierman *et al.* 1983
Loss of fish and wildlife habitat	Chemistry, bioaccumulation, toxicity, benthos, stability	Comparison to reference conditions, weight of evidence	Minns *et al.* 1996

*Physical sediment characteristics, quiescent versus energetic site characteristics, etc.

Table 5.1. Sediment sampling and analysis plan outline and checklist (from WDOE 1995).

Introduction and Background Information

- Site history
- Regulatory framework (e.g., NPDES, MTCA, SMS, CERCLA)
- Summary of previous investigations, if any, of the site
- Location and characteristics of any current and/or historical wastewater or storm water discharge(s) at the site
- Location and characteristics of any current and/or historical wastewater or storm water discharge(s) in the local area
- Information on on-site waste disposal practices or chemical spills in the local area, if any
- Site location map showing the surrounding area
- Site map showing site features

Objectives and Design of the Sediment Investigation

- Objectives of the sediment investigation
- Overall design of the sediment investigation, including related investigations, if any
- Chemical analytes (including description of their relevance to the objectives and the regulatory framework)
- Biological tests (including description of their relevance to the objectives and the regulatory framework)
- Sampling station locations
  - Rationale for station locations
  - Site map(s) showing sampling stations and other pertinent features (e.g., bathymetry and current regime; outfall(s)/diffuser(s); authorized mixing zone(s), if any; sites of waste disposal, spills, or other activities that may have affected the sediments, such as sandblasting, boat repair, etc.;
  - Proposed reference stations
  - Table showing the water depth at each proposed station
  - Proposed depth(s) below the sediment surface where sediments will be collected

Field Sampling Methods

- Station positioning methods
- Sampling equipment
- Decontamination procedures
- Sample compositing strategy and methods
- Sample containers and labels
- Field documentation procedures
- Procedures for disposal of contaminated sediments

Sample Handling Procedures

- Sample storage requirements (e.g., conditions, maximum holding times) for each type of sample
- Chain-of-custody procedures
- Delivery of samples to analytical laboratories

Table 5.1. Sediment sampling and analysis plan outline and checklist (from WDOE 1995).

Laboratory Analytical Methods
- Chemical analyses and target detection limits
- Biological analyses
- Corrective actions

Quality Assurance and Quality Control Requirements
- QA/QC for chemical analyses
- QA/QC for biological analysis
- Data quality assurance review procedures

Data Analysis, Record Keeping, and Reporting Requirements
- Analysis of sediment chemistry data
- Analysis of biological test data
- Data interpretation
- Record keeping procedures
- Reporting procedures

Health and Safety Plan (required for cleanup investigations)
- Description of tasks
- Key personnel and responsibilities
- Chemical and physical hazards
- Safety and health risk analysis for each task
- Air monitoring plan
- Personal protective equipment
- Work zones
- Decontamination procedures
- Disposal procedures for contaminated media and equipment
- Safe work procedures
- Standard operating procedures
- Contingency plan
- Personnel training requirements
- Medical surveillance program
- Record keeping procedures

Schedule
- Table or figure showing key project milestones

Project Team and Responsibilities
- Description of sediment sampling program personnel
- Table identifying the project team members and their responsibilities

References
- List of references

Table 5.2. Advantages and disadvantages of various sediment samplers (from WDOE 1995).

Sampler	Sediment Depth Sampled	Advantages	Disadvantages
Surface Sediment Samplers			
van Veen or Young grab	0-3 cm	Useful in deep water and on most substrates. Young grab coated with inert polymer. Large sediment volume obtained. May be subsampled through lid.	may occur during sampling. Incomplete jaw closure winch.
Ponar grab	0-10 cm	Commonly used. Large volume of sediment obtained. Adequate on most substrates. Weight allows use in deep waters. Good sediment penetration.	may occur during sampling. Incomplete jaw closure occurs occasionally. Heavy and requires a winch.
Petite Ponar grab	0-10 cm	Similar in design to the Ponar grab, but smaller and more easily handled from a small boat. Can be deployed by hand without a winch in shallow water.	Small volume. Loss of fine surface sediments and sediment integrity may occur during sampling. winch in deeper water.
Ekman or box dredge	0-10 cm	Relatively large volume of sediment may be obtained. May be subsampled through lid. Lid design reduces loss of surficial sediments as compared to many dredges. Usable in moderately compacted sediments of varying grain sizes.	Loss of fine surface sediments may occur during disrupted.
Petersen grab	0-30 cm	Large sediment volume obtained from most substrates in deep waters.	
Orange-peel grab	0-30 cm	Large sediment volume obtained from most substrates. Efficient closure.	Requires winch.

Table 5.2. **Advantages and disadvantages of various sediment samplers (from WDOE 1995).**

Sampler	**Sediment Depth Sampled**	**Advantages**	**Disadvantages**
Shipek grab	0-10 cm	Adequate on most substrates.	Small volume. Loss of fine surface sediments and sampling.
Sediment Corers			
Vibrocorer	to >200 cm	Samples deep sediment for historical analyses. Samples consolidated sediments.	integrity slightly disrupted.
Impact corer	to >200 cm	Samples deep sediment for historical analyses. Samples consolidated sediments.	Large impact corers may be expensive and require disrupted.
Box corer	0-30 cm	Maintains sediment layering of large volume of sediment. Fine surface sediments retained relatively well. Quantitative sampling allowed. Excellent control of depth of penetration.	sampling very coarse sediments.
Hand and gravity corers	0-30 cm	Maintain sediment layering of the inner core. Fine surface sediments retained by hand corer. Replicate samples efficiently obtained. Removable liners. Inert liners may be used. Quantitative sampling allowed.	consolidated sediments.
Piston corer	to 20 m	Samples deep sediment for historical analyses. Samples consolidated sediments.	integrity slightly disrupted.

Table 5.3. Minimum sediment samples sizes and acceptable containers for physical/chemical analyses and sediment toxicity tests (from WDOE 1995).

Sample Type	Minimum Sample Size[a]	Container Type[b]
Physical/Chemical Analyses		
Grain size	100–150 g	P,G
Total solids	50 g	P,G
Total volatile solids	50 g	P,G[c]
Total organic carbon	25 g	P,G
Ammonia	25 g	P,G
Total sulfides	50 g	P,G[c]
Oil and grease	100 g	G
Metals (except mercury)	50 g	P,G
Mercury	1 g	P,G
Volatile organic compounds	50 g	G,T[c]
Semivolatile organic compounds	50–100 g	G
Pesticides and PCBs	50–100 g	G,T
Toxicity Tests		
Amphipod (*Hyalella azteca*)	0.1 L per replicate (0.8 L per station)	G
Mayfly (*Hexagenia limbata*)	0.2 L per replicate (1.0 L per station)	G
Midge (*Chironomus tentans*)	0.1 L per replicate (0.8 L per station)	G
Frog embryo *(Xenopus laevis)*	45 g (dry weight) per station	G
Microtox® solid phase or deionized water	200 g (wet weight) per station	G

[a] Recommended field sample sizes (wet weight basis) for one laboratory analysis. If additional laboratory analyses are required (e.g., laboratory replicates, allowance for having to repeat an analysis), the field sample size should be increased accordingly. For some chemical analyses, smaller sample sizes may be used if comparable sensitivity can be obtained by adjusting instrumentation, extract volume, or other factors of the analysis.

[b] P - linear polyethylene; G - borosilicate glass; T - polytetrafluorethylene (PTFE, Teflon®)-lined cap.

[c] No headspace or air pockets should remain. If such samples are frozen in glass containers, breakage of the container is likely to occur.

Table 5.4. Storage temperatures and maximum holding times for physical/chemical analyses and sediment toxicity tests (from WDOE 1995).

Sample Type	Storage Temperature	Maximum Holding Time
Grain Size	Cool, 4°C	6 months
Total solids	Cool, 4°C Freeze, -18°C	14 days 6 months
Total volatile solids	Cool, 4°C Freeze, -18°C	14 days 6 months
Total organic carbon	Cool, 4°C Freeze, -18°C	14 days 6 months
Ammonia	Cool, 4°C	7 days
Total sulfides	Cool, 4°C (1 N zinc acetate)	7 days
Oil and grease	Cool, 4°C (HCl) Freeze, -18°C (HCl)	28 days 6 months
Metals (except mercury)	Cool, 4°C Freeze, -18°C	6 months 2 years
Mercury	Freeze, -18°C	28 days
Semivolatile organic compounds; pesticides and PCBs; PCDDs/PCDFs	Cool, 4°C Freeze, -18°C	10 days 1 year
after extraction	Cool, 4°C	40 days
Volatile organic compounds	Cool, 4°C Freeze, -18°C	14 days 14 days
Sediment toxicity tests	Cool, 4°C	2 weeks[a]
	Cool, 4°C, nitrogen atmosphere	8 weeks[a]

HCl - hydrochloric acid; PCB - polychlorinated biphenyl; PCDD - polychlorinated dibenzo-p-dioxin; PCDF - polychlorinated dibenzofuran.

[a] The PSEP (1995) protocols recommend a maximum holding time of 2 weeks, but recognize that it may be necessary under certain circumstances to extend the holding time to accommodate a tiered testing strategy in which chemical analyses are conducted prior to toxicity testing. The PSDDA program, for example, allows sediments to be stored in the dark in a nitrogen atmosphere at 4°C for up to 8 weeks.

Table 5.5. Quality control procedures for organic analyses (from WDOE 1995).

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Instrument Quality Assurance/Quality Control			
Initial Calibration	As recommended by PSEP (1989a) and specified in analytical protocol	≤30 %RSD for SVOCs and VOCs; ≤20 %RSD for PCBs. Relative response factors ≥0.05 for SVOCs and VOCs	Laboratory to recalibrate and reanalyze affected samples
Continuing Calibration	After every 10–12 samples (6 samples for PCBs) or every 12 hours (6 hours for PCBs), whichever is more frequent, and after the last sample of each work shift	≤25 %D for SVOCs and VOCs; ≤ 15 %D for PCBs. Relative response factors ≥ 0.05 for SVOCs and VOCs	Laboratory to recalibrate and reanalyze affected samples
Method Quality Assurance/Quality Control			
Holding Times	Not applicable	1 year (samples stored frozen [-18°C]) or 14 days (samples stored at 4°C) for SVOCs and PCBs; analyze extract within 40 days; 14 days (samples stored at 4°C) for VOCs	Qualify data or collect fresh samples
Method Blank	With every extraction batch; every 12-hour shift for VOCs	Analyte concentration >PQL (the LOD constitutes the warning limit)	Laboratory to eliminate or greatly reduce contamination; reanalyze affected samples
Surrogate Compounds	Added to every sample as specified in analytical protocol	EPA CLP control limits	Laboratory to follow EPA CLP protocols (reanalyzes or reextraction may be required)
Matrix Spike Sample and Matrix Spike Duplicate	With every sample batch or every 20 samples, whichever is more frequent	Recovery of 50–150 percent; precision of ≤50 RPD	Follow EPA CLP protocols

Table 5.5. Quality control procedures for organic analyses (from WDOE 1995).

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Method Quality Assurance/Quality Control (cont.)			
Laboratory Control Sample	With every sample batch or every 20 samples, whichever is more frequent	Recovery of 50–150 percent	Laboratory to correct problem and reanalyze affected samples
Internal Standards	Added to every sample as specified in analytical protocol	Area response of 50–200 percent of calibration standard; retention time within 30 seconds of calibration standard	Laboratory to correct problem and reanalyze affected samples
Detection Limits	Not applicable	Target detection limits should be established at one-half of the TEC values (MacDonald *et al.* 2000)	Laboratory must initiate corrective actions (which may include additional cleanup steps as well as other measures, see) and contact the QA/QC coordinator and/or project manager immediately.
Field Quality Assurance/Quality Control			
Field Replicates	At project manager's discretion	Not applicable	Not applicable
Blind Certified Reference Material	Overall frequency of 5 percent of field samples	Within 95 percent confidence interval of true value	At project manager's discretion: discuss results with laboratory; qualify sample results

CLP - Contract Laboratory Program; EPA - U.S. Environmental Protection Agency; LOD - limit of detection; PCB - polychlorinated biphenyl; PQL - protection quantification limit; RPD - relative percent difference; RSD - relative standard deviation; SVOC - semivolatile organic compound; VOC - volatile organic compound; QA/QC - quality assurance/quality control.

Table 5.6. Quality control procedures for metal analyses (from WDOE 1995).

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Instrument Quality Assurance/Quality Control			
Initial Calibration	Daily	Correlation coefficient > 0.995	Laboratory to recalibrate the instrument and reanalyze any affected samples
Initial Calibration Verification	Immediately after initial calibration	90–110 percent recovery (80–120 percent for mercury)	Laboratory to resolve discrepancy prior to sample analysis
Continuing Calibration Verification	After every 10 samples or every 2 hours, whichever is more frequent, and after the last sample	90–110 percent recovery (80–120 percent for mercury)	Laboratory to recalibrate and reanalyze affected samples
Initial and Continuing Calibration Blanks	Immediately after initial calibration, then 10 percent of samples or every 2 hours, whichever is more frequent, and after the last sample	Analyte concentration ≤CRDL	Laboratory to recalibrate and reanalyze affected samples
ICP Interelement Interference Check Sample	At the beginning and end of each analytical sequence or twice per 8 hour shift, whichever is more frequent	80–120 percent of the true value	Laboratory to correct problem, recalibrate, and reanalyze affected samples
Method Quality Assurance/Quality Control			
Holding Times	Not applicable	6 months if samples are held at 4°C; 2 years if samples are frozen (-18°C); 28 days for mercury regardless of whether samples are held at 4°C or frozen	Qualify data or collect fresh samples

Table 5.6. Quality control procedures for metal analyses (from WDOE 1995).

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Method Quality Assurance/Quality Control (cont.)			
Method Blanks	With every sample batch or every 20 samples, whichever is more frequent	Analyte concentration ≤CRDL	Laboratory to redigest and reanalyze samples with analyte concentrations ≤10 times the highest method blank
Laboratory Control Sample	With every sample batch or every 20 samples, whichever is more frequent	EPA control limits (varies with laboratory control sample)	Laboratory to correct problem and redigest and reanalyze affected samples
Matrix Quality Assurance/Quality Control			
Matrix Spike Sample	With every sample batch or every 20 samples, whichever is more frequent	75–125 percent recovery	Laboratory may be able to correct or minimize problem; or qualify and accept data
Duplicate Sample Analysis	With every sample batch or every 20 samples, whichever is more frequent	±35 RPD (2 times CRDL for sample duplicate results >5 times CRDL)	Laboratory may be able to correct or minimize problem; or qualify and accept data as reported
Method of Standard Additions (for GFAA)	As required when analytical spike recovery fails quality control limits (EPA current CLP statement of work)	Correlation coefficient ≥0.995	Qualify and accept data as reported
Detection Limits	Not applicable	Target detection limits should be established at one-half of the TEC values (MacDonald *et al.* 2000)	Laboratory must initiate corrective actions and contact the QA/QC coordinator and/or the project manager immediately

Table 5.6. **Quality control procedures for metal analyses (from WDOE 1995).**

Quality Control Procedure	Frequency	Control Limit	Corrective Action
Matrix Quality Assurance/Quality Control (cont.)			
Field Replicates	At project manager's discretion	±35 RPD (2 times CRDL for sample duplicate results >5 times CRDL)	Examine laboratory replicate results to rule out analytical imprecision; examine and modify sample homogenization procedures in the field
Cross-Contamination Blanks	At project manager's discretion	Analyte concentration ≤CRDL	Examine method blank results to rule out laboratory contamination; modify sample collection and equipment decontamination procedures
Blind Certified Reference Material	Overall frequency of 5 percent of field samples	80–120 percent recovery	Project Manager decision: discuss results with laboratory; qualify sample results

CLP - Contract Laboratory Program (EPA); CRLD - contract required detection limit; EPA - U.S. Environmental Protection Agency; GFAA - graphite furnace atomic absorption; ICP - inductively coupled plasma-atomic emission spectrometry; RPD - relative percent difference; QA/QC - quality assurance/quality control.

Instrument and method QA/QC monitor the performance of the instrument and sample preparation procedures, and are the responsibility of the analytical laboratory. When an instrument or method control limit is exceeded, the laboratory is responsible for correcting the problem and reanalyzing the samples. Instrument and method QA/QC results reported in the final data package should always meet control limits (with a very small number of exceptions that apply to difficult analytes as specified by EPA for the CLP). If instrument and method QA/QC procedures meet control limits, laboratory procedures are deemed to be adequate. Matrix and field QA/QC procedures monitor matrix effects and field procedures and variability. Although poor analytical procedures may also result in poor spike recovery or duplicate results, the laboratory is not held responsible for meeting control limits for these QA/QC samples. Except in the possible case of unreasonably large exceedances, any reanalyses will be performed at the request and expense of the project manager.

Table 5.7. Quality control procedures for conventional analyses (from WDOE 1995).

Analyte	Suggested Control Limit						
	Initial Calibration	Continuing Calibration	Calibration Blanks	Laboratory Control Samples	Matrix Spikes	Laboratory Triplicates	Method Blank
Ammonia	Correlation coefficient ≥ 0.995	90–110 percent recovery	Analyte concentration $\leq$CRDL	80–120 percent recovery	75–125 percent recovery	35 percent RSD	Analyte concentration $\leq$CRDL
Grain size	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	35 percent RSD	Analyte concentration $\leq$CRDL
Total organic carbon	Correlation coefficient ≥ 0.995	90–110 percent recovery	Analyte concentration $\leq$CRDL	80–120 percent recovery	75–125 percent recovery	35 percent RSD	Analyte concentration $\leq$CRDL
Total sulfides	Correlation coefficient ≥ 0.990	85–115 percent recovery	Not applicable	65–135 percent recovery	65–135 percent recovery	35 percent RSD	Analyte concentration $\leq$CRDL
Total solids	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	35 percent RSD	Analyte concentration $\leq$CRDL

CRLD - contract-required detection limit; EPA - U.S. Environmental Protection Agency;
relative standard deviation.

EPA and PSEP control limits are not available for conventional analytes. The control limits provided above a
analyses (Table 5.6), and an attempt has been made to take into consideration the expected analytical accuracy using PSEP
are exceeded is left to the Project Manager's discretion. The corrective action indicated for metals in Table 6.6 may be applied to conventional analytes.
When applicable, the QA/QC procedures indicated in this table should be completed at the same frequency as for metals analyses (Table 5.6).

Table 5.8. Examples of recommended test conditions for conducting freshwater sediment toxicity tests (from WDOE 1995).

Toxicity Test *Test Species*	Frequency of Water Quality		Control Limits		Control Samples			Performance Standards
	Temp, DO	Hardness, Alkalinity, Conductivity, pH, Ammonia	Temp (°C)	DO (% saturation)	Negative Control	Positive Control	Reference Sediment	
Amphipod *Hyalella azteca*	Daily	Beginning/end	23±1[a]	40–100	Clean sediment	Reference toxicant in freshwater	Yes	Mean mortality in control sediment <20%
Mayfly *Hexagenia limbata*	Daily	Beginning/end	20±2	Not applicable[b]	Clean sediment	Reference toxicant in freshwater	Yes	Mean mortality in control sediment <20%
Midge *Chironomus tentans*	Daily	Beginning/end	23±1[a]	40–100	Clean sediment	Reference toxicant in freshwater	Yes	Mean mortality in control sediment <30%
Frog embryo (FETAX) *Xenopus laevis*	DO at beginning/end	Beginning/end	24±2	Not applicable	FETAX solution	Reference toxicant in FETAX solution	Yes	Mean mortality in negative control <10%, or mean malformation occurrence in negative control <7%
Microtox® (solid phase) *Vibrio fisheri*[c]	Not applicable	Not applicable	15	Not applicable	Clean sediment	Reference toxicant	Yes	Determined by ecology on case-by-case basis.
Microtox® (deionized water elutriate) *Vibrio fisheri*[c]	Not applicable	Not applicable	15	Not applicable	Clean sediment	Reference toxicant	Yes	Determined by ecology on case-by-case basis.

DO - dissolved oxygen; Temp = temperature.

[a] The temperature o
The instantaneous temperature must always be within ±3°C of the desired temperature.

[b] Continuous aeration is required by the protocol, so the dissolved oxygen concentration should not be cause for concern.

[c] Formerly known as *Photobacterium phosphoreum* .

Note: more recent guidance on conducting freshwater toxicity tests is provided in USEPA (2000a) and ASTM (2001a; 2001b).

Table A2.1. Statutory needs for sediment quality assessment (from USEPA 2000c).

*Legislation	Description of Sediment Quality Assessment Need
CERCLA; BCWMA	* Assess need for remedial action with contaminated sediments; assess degree of cleanup required; disposition of sediment
CWA	* NPDES permitting, especially under Best Available Technology (BAT) in water-quality-limited water * Section 403(c) criteria for ocean discharges; mandatory additional requirements to protect marine environment * Section 301(g) waivers for publically owned treatment works (PTOWS) discharging to marine waters * Section 404 permits to dredge and fill activities (administered by the Corps of Engineers)
FIFRA	* Review uses of new and existing chemicals * Pesticide labeling and registration
MPRSA; CEPA	* Permits for ocean dumping
NEPA	* Preparation of environmental impact statements for projects with surface water discharges
TSCA	* Section 5: Pre-manufacture notice reviews for new chemicals * Section 4,5,6: Reviews for existing industrial chemicals
RCRA	* Assess suitability (and permit) on-land disposal or beneficial use of contaminated sediments considered "hazardous"

*CERCLA - Comprehensive Environmental Response, Compensation and Liability Act ("Superfund"); BCWMA - British Columbia Waste Management Act (Contaminated Sites Regulation); CEPA - Canadian Environmental Protection Act; CWA - Clean Water Act; FIFRA - Federal Insecticide, Fungicide, and Rodenticide Act; MPRSA - Marine Protection, Resources and Sanctuary Act; NEPA - National Environmental Policy Act; TSCA - Toxic Substances Control Act; RCRA - Resource Conservation and Recovery Act.

Figures

Figure 2.1. Overview of the process for designing and implementing sediment quality investigations.

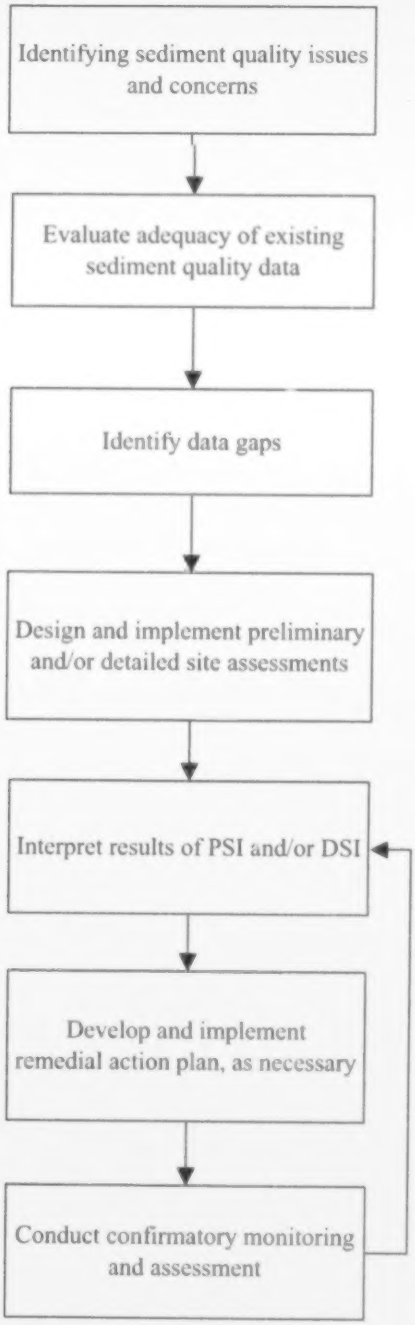

Identifying sediment quality issues and concerns
Evaluate adequacy of existing sediment quality data
Identify data gaps
Design and implement preliminary and/or detailed site assessments
Interpret results of PSI and/or DSI
Develop and implement remedial action plan, as necessary
Conduct confirmatory monitoring and assessment

Figure 2.2. Overview of the recommended process for managing sites with contaminated sediments.

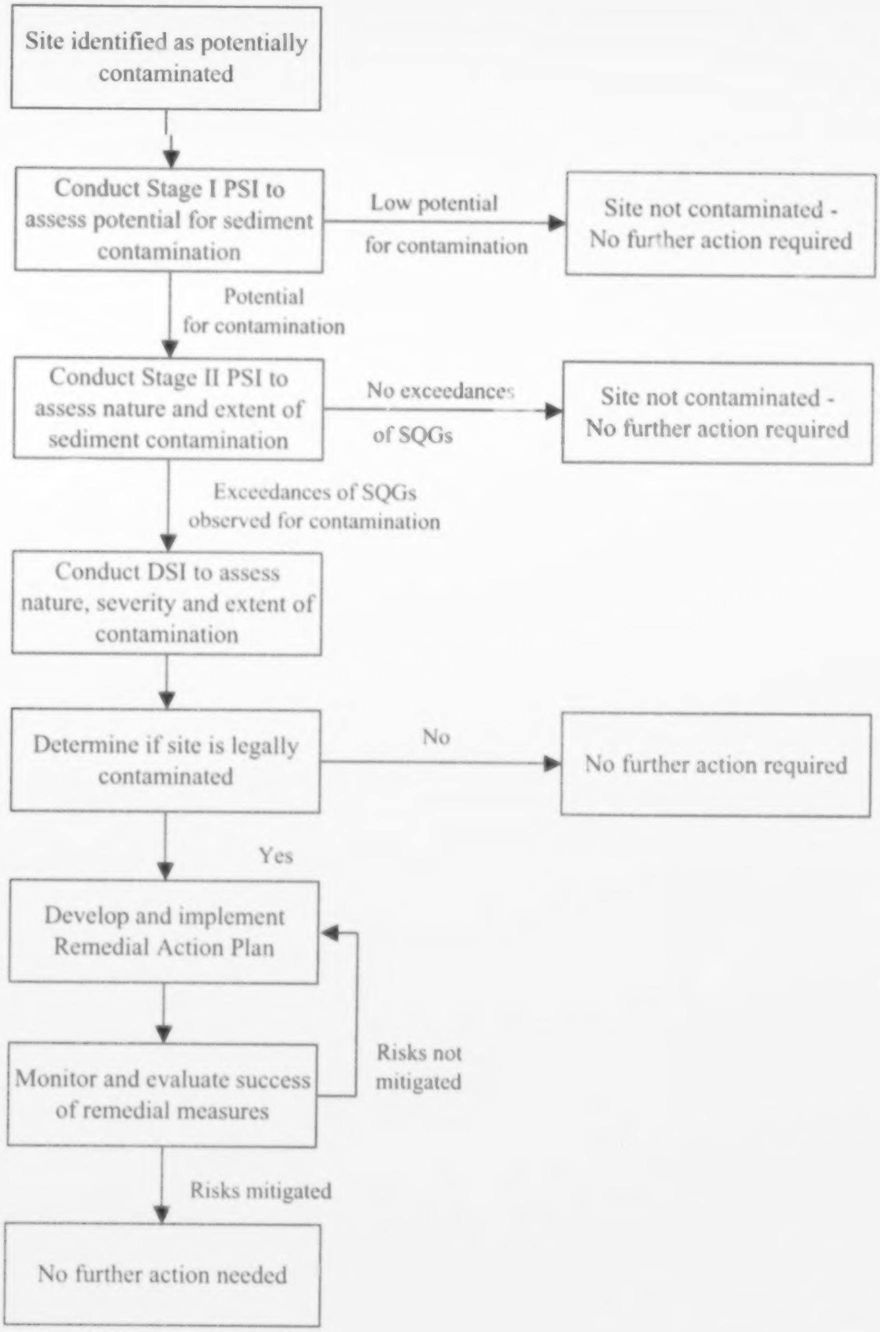

Site identified as potentially contaminated
Conduct Stage I PSI to assess potential for sediment contamination
Low potential for contamination
Site not contaminated - No further action required
Potential for contamination
Conduct Stage II PSI to assess nature and extent of sediment contamination
No exceedances of SQGs
Site not contaminated - No further action required
Exceedances of SQGs observed for contamination
Conduct DSI to assess nature, severity and extent of contamination
Determine if site is legally contaminated
No
No further action required
Yes
Develop and implement Remedial Action Plan
Monitor and evaluate success of remedial measures
Risks not mitigated
Risks mitigated
No further action needed

Figure 2.3. An overview of Stage I of the preliminary site investigation (PSI).

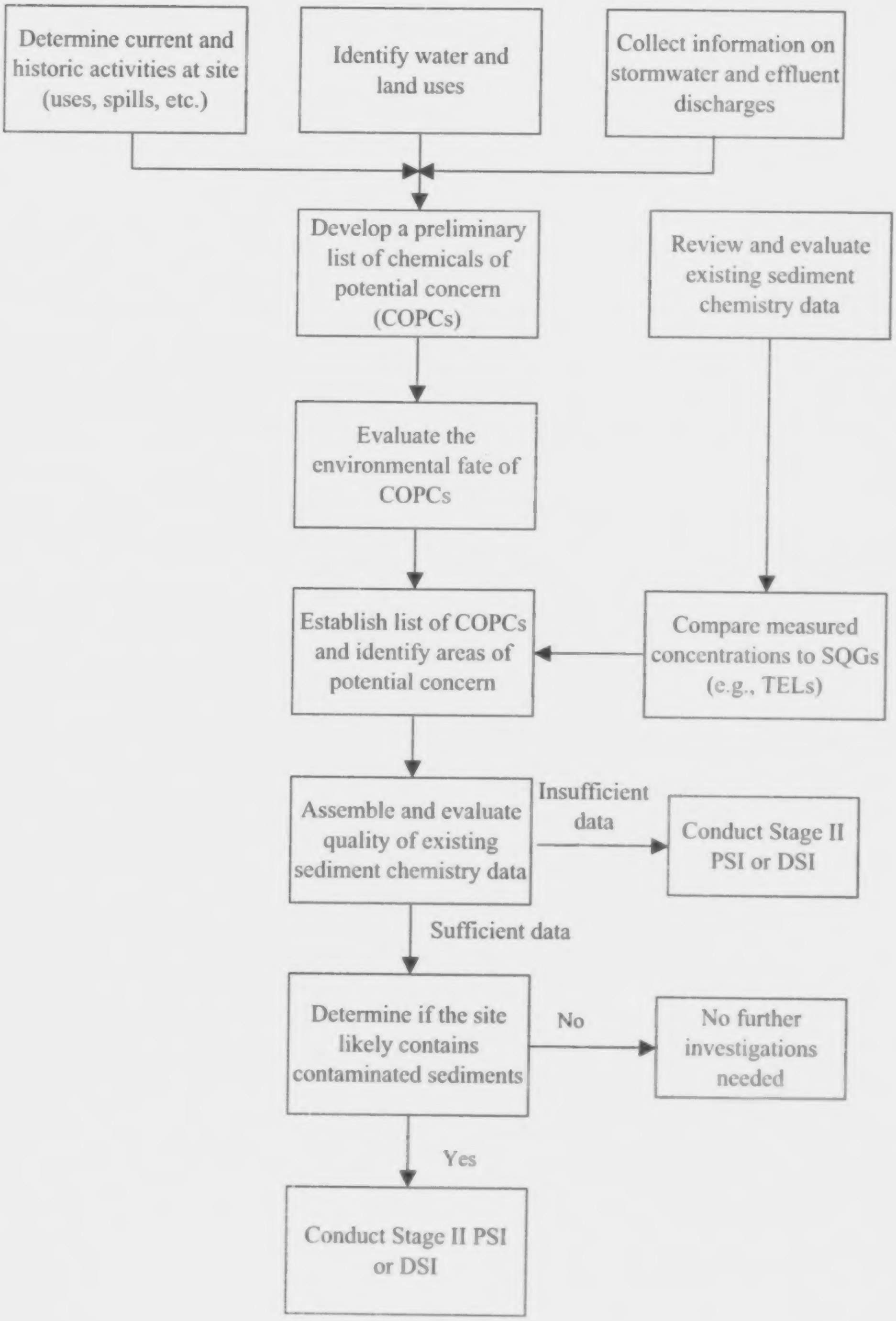

Determine current and historic activities at site (uses, spills, etc.)
Identify water and land uses
Collect information on stormwater and effluent discharges
Develop a preliminary list of chemicals of potential concern (COPCs)
Review and evaluate existing sediment chemistry data
Evaluate the environmental fate of COPCs
Establish list of COPCs and identify areas of potential concern
Compare measured concentrations to SQGs (e.g., TELs)
Assemble and evaluate quality of existing sediment chemistry data
Insufficient data
Conduct Stage II PSI or DSI
Sufficient data
Determine if the site likely contains contaminated sediments
No
No further investigations needed
Yes
Conduct Stage II PSI or DSI

Figure 2.4. An overview of Stage II of the preliminary site investigation (PSI). A Stage II PSI is conducted if the results of the first stage of the PSI indicates that sediments are

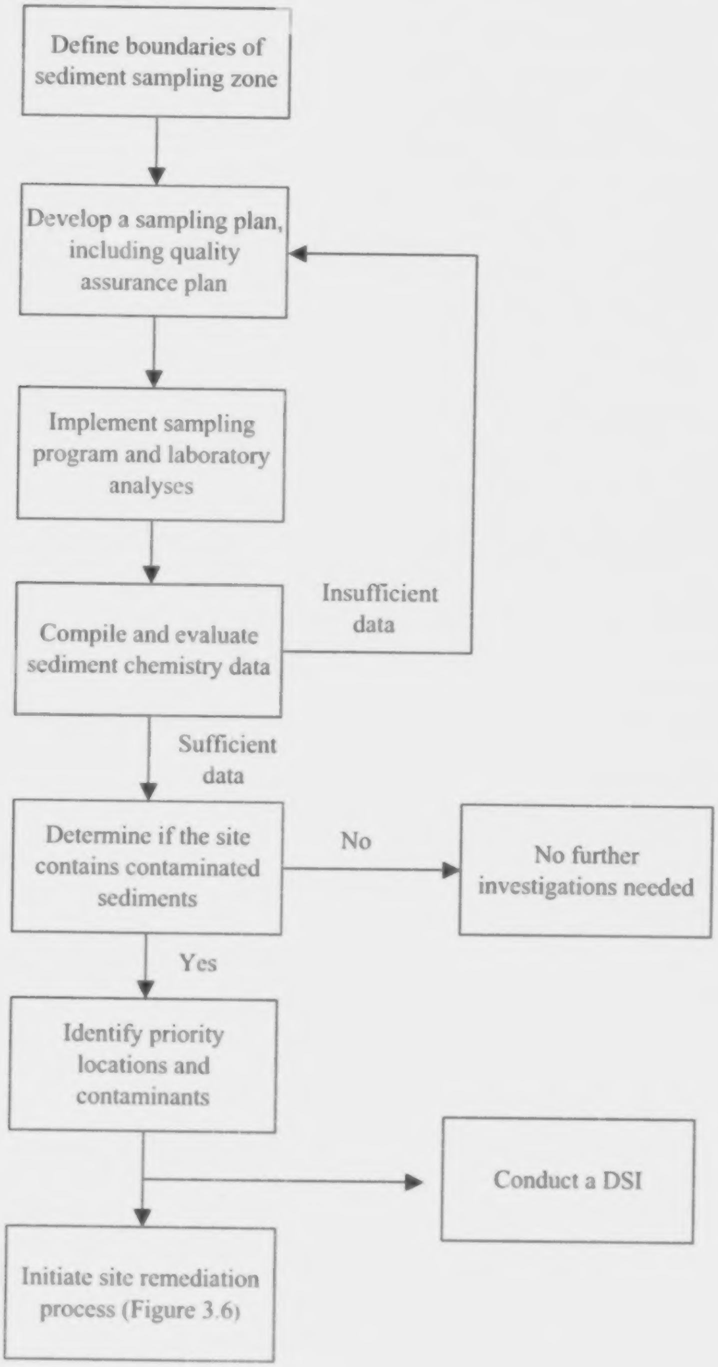

Define boundaries of sediment sampling zone
Develop a sampling plan, including quality assurance plan
Implement sampling program and laboratory analyses
Compile and evaluate sediment chemistry data
Insufficient data
Sufficient data
Determine if the site contains contaminated sediments
No
No further investigations needed
Yes
Identify priority locations and contaminants
Conduct a DSI
Initiate site remediation process (Figure 3.6)

Figure 2.5. An overview of the detailed site investigation (DSI).

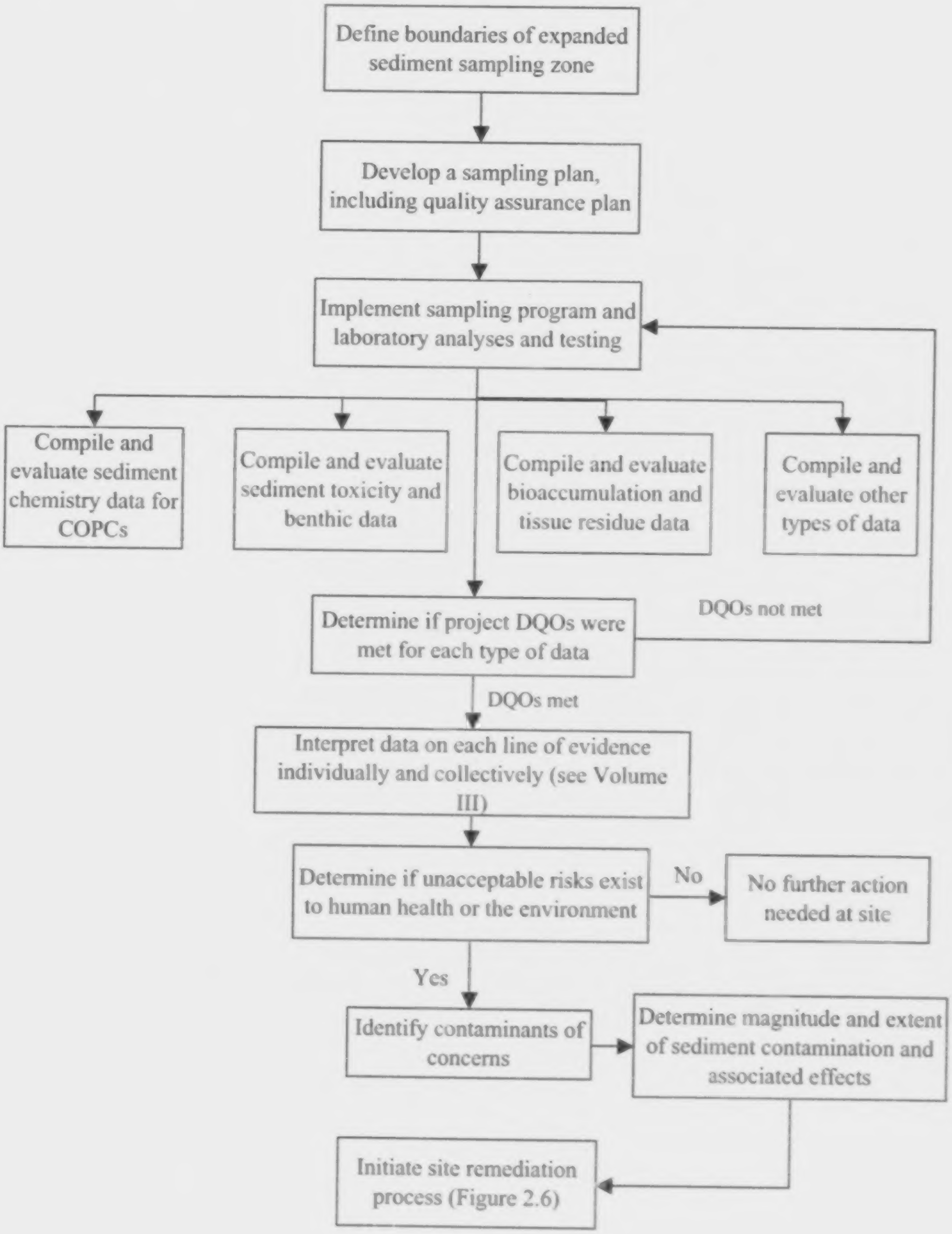

Define boundaries of expanded sediment sampling zone
Develop a sampling plan, including quality assurance plan
Implement sampling program and laboratory analyses and testing
Compile and evaluate sediment chemistry data for COPCs
Compile and evaluate sediment toxicity and benthic data
Compile and evaluate bioaccumulation and tissue residue data
Compile and evaluate other types of data
Determine if project DQOs were met for each type of data
DQOs not met
DQOs met
Interpret data on each line of evidence individually and collectively (see Volume III)
Determine if unacceptable risks exist to human health or the environment
No
No further action needed at site
Yes
Identify contaminants of concerns
Determine magnitude and extent of sediment contamination and associated effects
Initiate site remediation process (Figure 2.6)

Figure 2.6. An overview of the contaminated site remediation process.

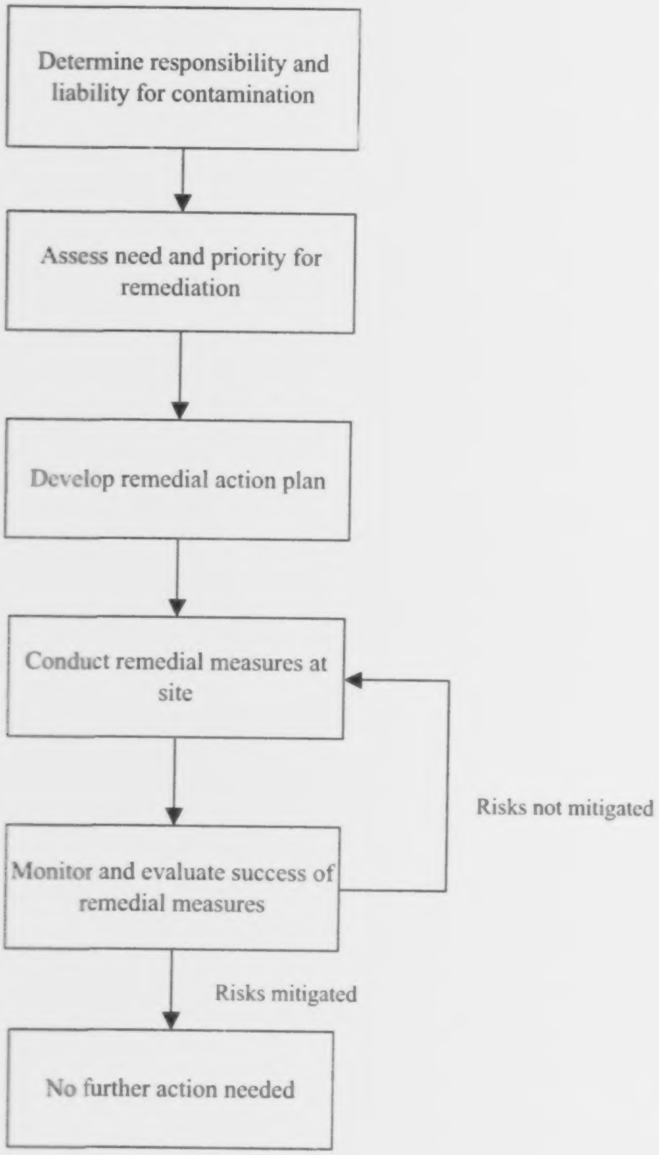

Determine responsibility and liability for contamination
Assess need and priority for remediation
Develop remedial action plan
Conduct remedial measures at site
Risks not mitigated
Monitor and evaluate success of remedial measures
Risks mitigated
No further action needed

Figure A1.1. Overview of the tiered approach for assessing the environmental effects of dredged material management alternatives (from USEPA and USACE 1998a).

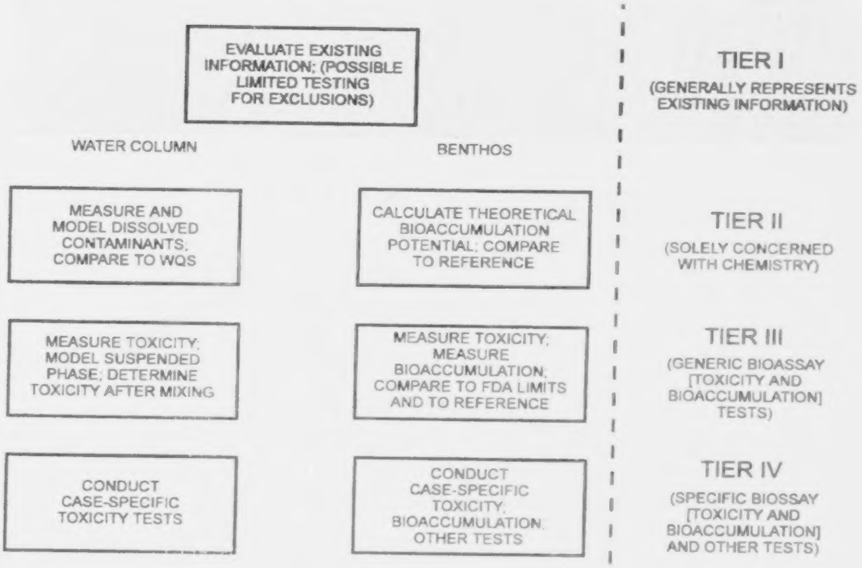

EVALUATE EXISTING INFORMATION; (POSSIBLE LIMITED TESTING FOR EXCLUSIONS)
WATER COLUMN
BENTHOS
MEASURE AND MODEL DISSOLVED CONTAMINANTS; COMPARE TO WQS
CALCULATE THEORETICAL BIOACCUMULATION POTENTIAL; COMPARE TO REFERENCE
MEASURE TOXICITY; MODEL SUSPENDED PHASE; DETERMINE TOXICITY AFTER MIXING
MEASURE TOXICITY; MEASURE BIOACCUMULATION; COMPARE TO FDA LIMITS AND TO REFERENCE
CONDUCT CASE-SPECIFIC TOXICITY TESTS
CONDUCT CASE-SPECIFIC TOXICITY; BIOACCUMULATION; OTHER TESTS
TIER I
(GENERALLY REPRESENTS EXISTING INFORMATION)
TIER II
(SOLELY CONCERNED WITH CHEMISTRY)
TIER III
(GENERIC BIOASSAY [TOXICITY AND BIOACCUMULATION] TESTS)
TIER IV
(SPECIFIC BIOSSAY [TOXICITY AND BIOACCUMULATION] AND OTHER TESTS)

Figure A1.1. **Overview of the tiered approach for assessing the environmental effects of dredged material management alternatives (from USEPA and USACE 1998a).**

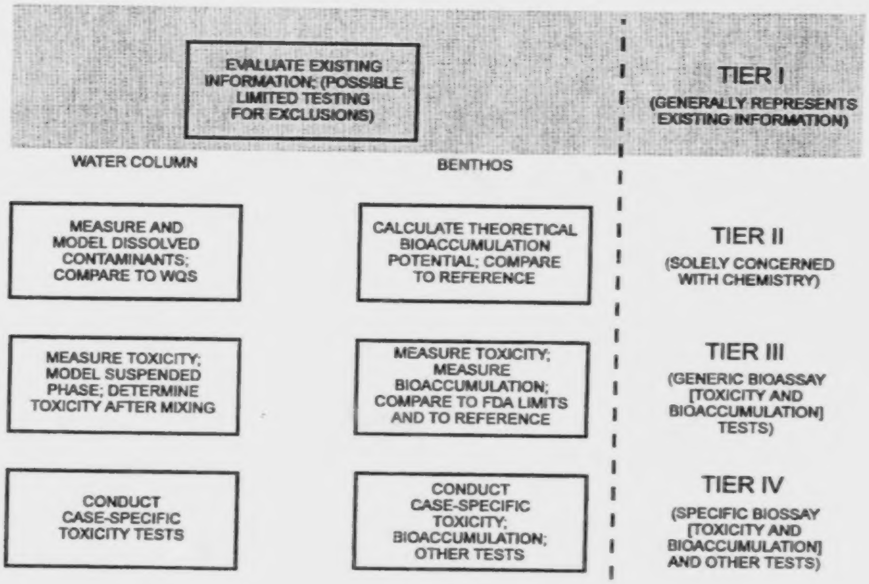

EVALUATE EXISTING INFORMATION; (POSSIBLE LIMITED TESTING FOR EXCLUSIONS)
TIER I
(GENERALLY REPRESENTS EXISTING INFORMATION)
WATER COLUMN
BENTHOS
MEASURE AND MODEL DISSOLVED CONTAMINANTS; COMPARE TO WQS
CALCULATE THEORETICAL BIOACCUMULATION POTENTIAL; COMPARE TO REFERENCE
TIER II
(SOLELY CONCERNED WITH CHEMISTRY)
MEASURE TOXICITY; MODEL SUSPENDED PHASE; DETERMINE TOXICITY AFTER MIXING
MEASURE TOXICITY; MEASURE BIOACCUMULATION; COMPARE TO FDA LIMITS AND TO REFERENCE
TIER III
(GENERIC BIOASSAY [TOXICITY AND BIOACCUMULATION] TESTS)
CONDUCT CASE-SPECIFIC TOXICITY TESTS
CONDUCT CASE-SPECIFIC TOXICITY; BIOACCUMULATION; OTHER TESTS
TIER IV
(SPECIFIC BIOSSAY [TOXICITY AND BIOACCUMULATION] AND OTHER TESTS)

Figure A1.2. Simplified overview of tiered approach to evaluating potential impact of aquatic disposal of dredged material (from USEPA and USACE 1998a).

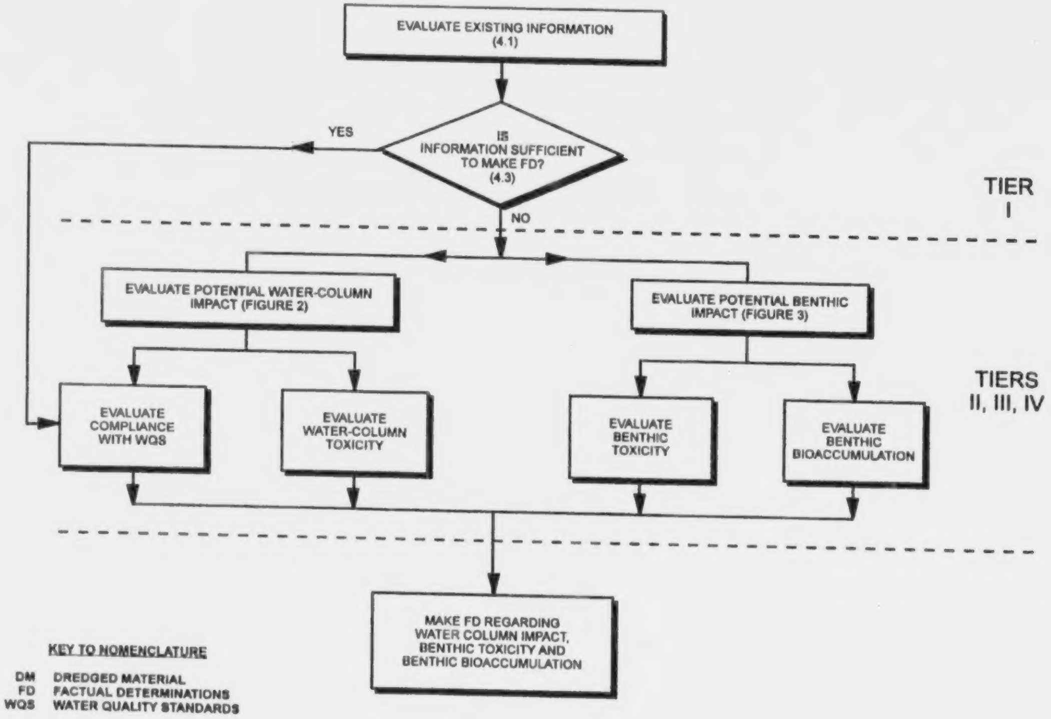

EVALUATE EXISTING INFORMATION (4.1)
IS INFORMATION SUFFICIENT TO MAKE FD? (4.3)
YES
NO
TIER I
EVALUATE POTENTIAL WATER-COLUMN IMPACT (FIGURE 2)
EVALUATE POTENTIAL BENTHIC IMPACT (FIGURE 3)
TIERS II, III, IV
EVALUATE COMPLIANCE WITH WQS
EVALUATE WATER-COLUMN TOXICITY
EVALUATE BENTHIC TOXICITY
EVALUATE BENTHIC BIOACCUMULATION
MAKE FD REGARDING WATER COLUMN IMPACT, BENTHIC TOXICITY AND BENTHIC BIOACCUMULATION
KEY TO NOMENCLATURE
DM DREDGED MATERIAL
FD FACTUAL DETERMINATIONS
WQS WATER QUALITY STANDARDS

Figure A1.3. Illustration of the tiered approach to evaluating potential water column impacts of dredged material (from USEPA and USACE 1998a).

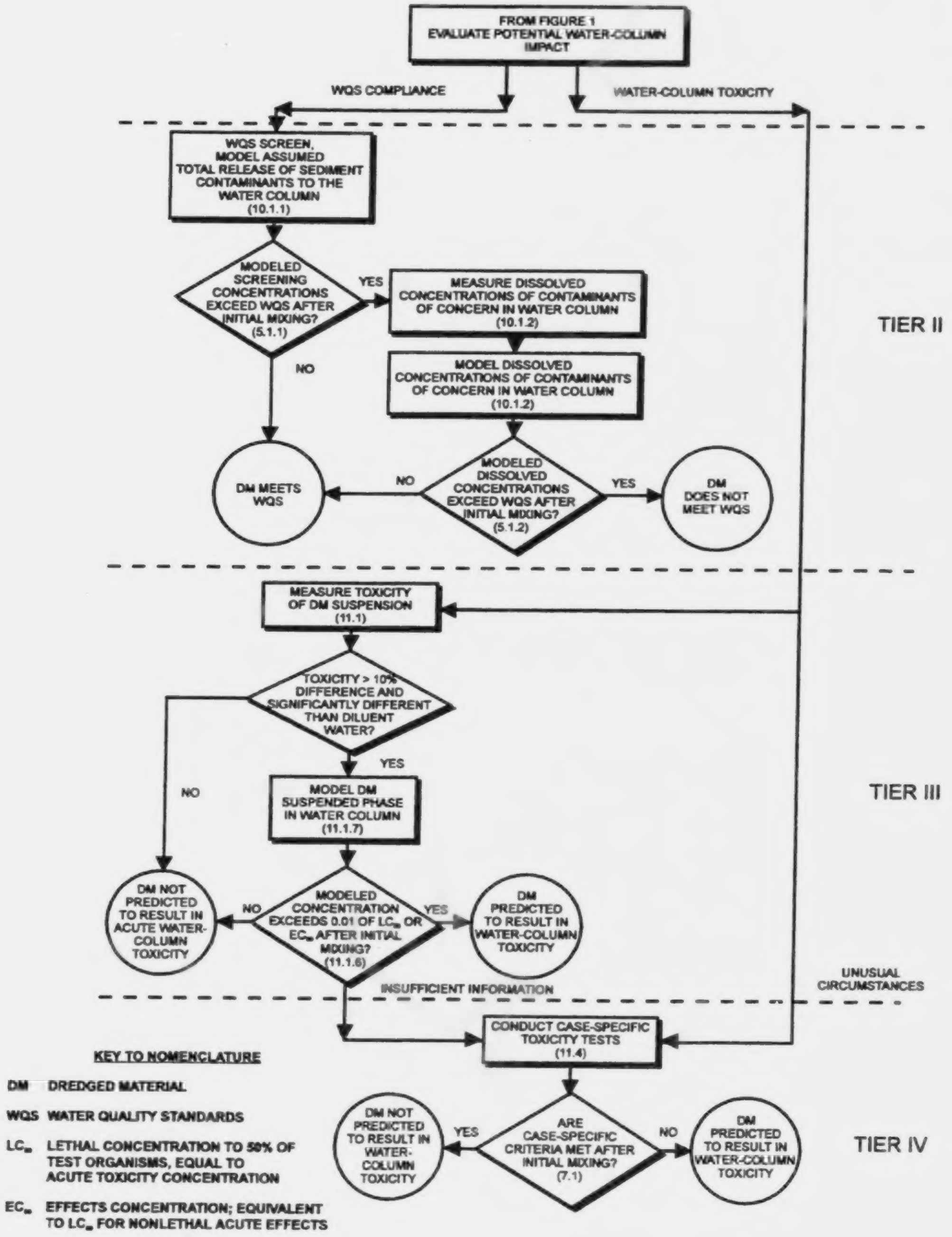
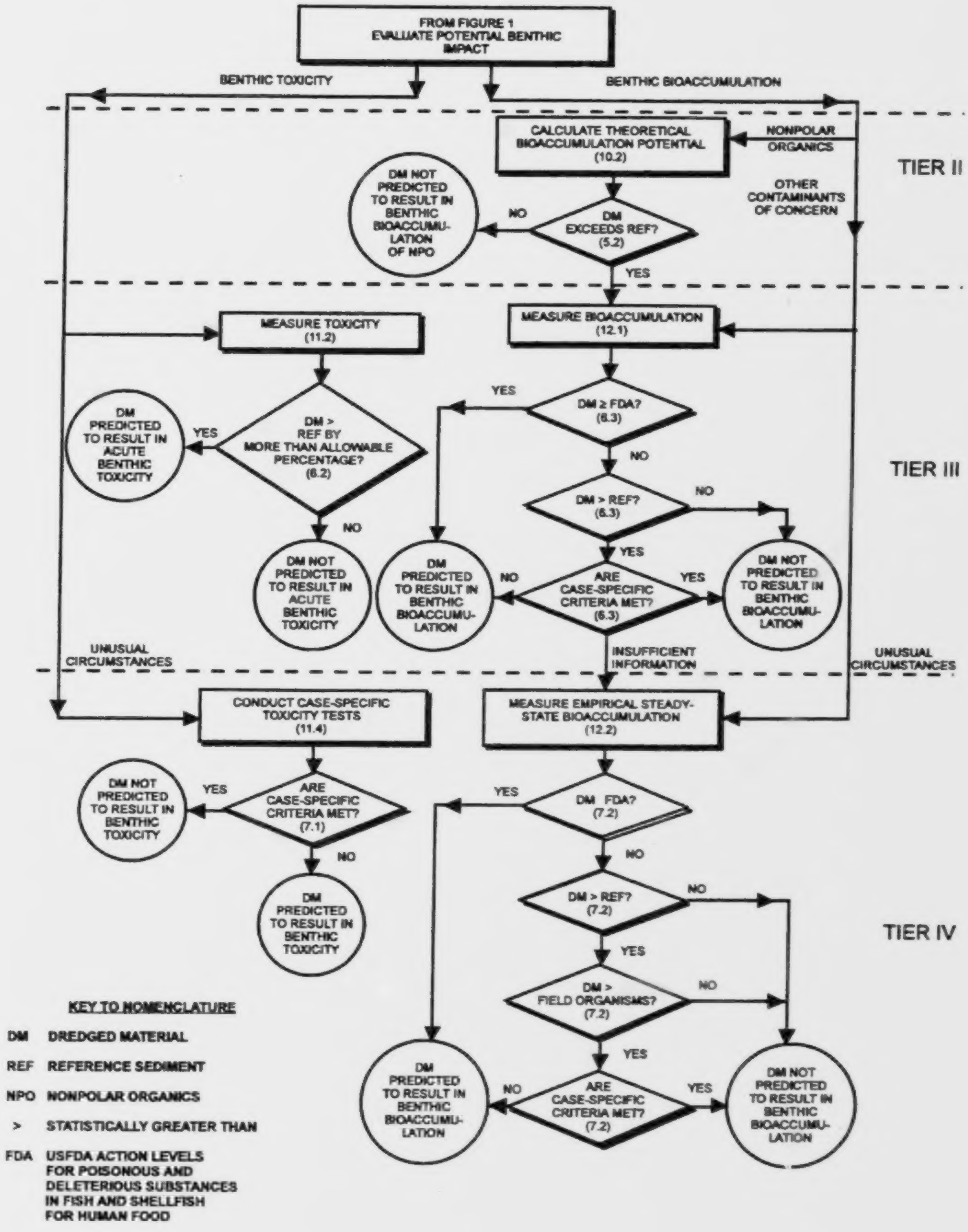

FROM FIGURE 1
EVALUATE POTENTIAL WATER-COLUMN IMPACT
WQS COMPLIANCE
WATER-COLUMN TOXICITY
WQS SCREEN, MODEL ASSUMED TOTAL RELEASE OF SEDIMENT CONTAMINANTS TO THE WATER COLUMN (10.1.1)
MODELED SCREENING CONCENTRATIONS EXCEED WQS AFTER INITIAL MIXING? (5.1.1)
YES
MEASURE DISSOLVED CONCENTRATIONS OF CONTAMINANTS OF CONCERN IN WATER COLUMN (10.1.2)
TIER II
NO
MODEL DISSOLVED CONCENTRATIONS OF CONTAMINANTS OF CONCERN IN WATER COLUMN (10.1.2)
DM MEETS WQS
NO
MODELED DISSOLVED CONCENTRATIONS EXCEED WQS AFTER INITIAL MIXING? (5.1.2)
YES
DM DOES NOT MEET WQS
MEASURE TOXICITY OF DM SUSPENSION (11.1)
TOXICITY > 10% DIFFERENCE AND SIGNIFICANTLY DIFFERENT THAN DILUENT WATER?
YES
NO
MODEL DM SUSPENDED PHASE IN WATER COLUMN (11.1.7)
TIER III
DM NOT PREDICTED TO RESULT IN ACUTE WATER-COLUMN TOXICITY
NO
MODELED CONCENTRATION EXCEEDS 0.01 OF LC_{50} OR EC_{50} AFTER INITIAL MIXING? (11.1.6)
YES
DM PREDICTED TO RESULT IN WATER-COLUMN TOXICITY
INSUFFICIENT INFORMATION
UNUSUAL CIRCUMSTANCES
CONDUCT CASE-SPECIFIC TOXICITY TESTS (11.4)
KEY TO NOMENCLATURE
DM DREDGED MATERIAL
WQS WATER QUALITY STANDARDS
LC_{50} LETHAL CONCENTRATION TO 50% OF TEST ORGANISMS, EQUAL TO ACUTE TOXICITY CONCENTRATION
EC_{50} EFFECTS CONCENTRATION; EQUIVALENT TO LC_{50} FOR NONLETHAL ACUTE EFFECTS
DM NOT PREDICTED TO RESULT IN WATER-COLUMN TOXICITY
YES
ARE CASE-SPECIFIC CRITERIA MET AFTER INITIAL MIXING? (7.1)
NO
DM PREDICTED TO RESULT IN WATER-COLUMN TOXICITY
TIER IV

Figure A1.4. Illustration of the tiered approach to evaluating potential benthic impacts of deposited dredged material (from USEPA and USACE 1998a).


FROM FIGURE 1
EVALUATE POTENTIAL BENTHIC IMPACT
BENTHIC TOXICITY
BENTHIC BIOACCUMULATION
TIER II
CALCULATE THEORETICAL BIOACCUMULATION POTENTIAL (10.2)
NONPOLAR ORGANICS
OTHER CONTAMINANTS OF CONCERN
DM EXCEEDS REF? (5.2)
NO
DM NOT PREDICTED TO RESULT IN BENTHIC BIOACCUMU-LATION OF NPO
YES
TIER III
MEASURE TOXICITY (11.2)
MEASURE BIOACCUMULATION (12.1)
DM > REF BY MORE THAN ALLOWABLE PERCENTAGE? (6.2)
YES
DM PREDICTED TO RESULT IN ACUTE BENTHIC TOXICITY
NO
DM NOT PREDICTED TO RESULT IN ACUTE BENTHIC TOXICITY
DM ≥ FDA? (6.3)
YES
NO
DM > REF? (6.3)
NO
YES
ARE CASE-SPECIFIC CRITERIA MET? (6.3)
NO
DM PREDICTED TO RESULT IN BENTHIC BIOACCUMU-LATION
YES
DM NOT PREDICTED TO RESULT IN BENTHIC BIOACCUMU-LATION
UNUSUAL CIRCUMSTANCES
INSUFFICIENT INFORMATION
UNUSUAL CIRCUMSTANCES
CONDUCT CASE-SPECIFIC TOXICITY TESTS (11.4)
ARE CASE-SPECIFIC CRITERIA MET? (7.1)
YES
DM NOT PREDICTED TO RESULT IN BENTHIC TOXICITY
NO
DM PREDICTED TO RESULT IN BENTHIC TOXICITY
MEASURE EMPIRICAL STEADY-STATE BIOACCUMULATION (12.2)
DM FDA? (7.2)
YES
NO
DM > REF? (7.2)
NO
YES
DM > FIELD ORGANISMS? (7.2)
NO
YES
ARE CASE-SPECIFIC CRITERIA MET? (7.2)
NO
DM PREDICTED TO RESULT IN BENTHIC BIOACCUMU-LATION
YES
DM NOT PREDICTED TO RESULT IN BENTHIC BIOACCUMU-LATION
TIER IV
KEY TO NOMENCLATURE
DM DREDGED MATERIAL
REF REFERENCE SEDIMENT
NPO NONPOLAR ORGANICS
> STATISTICALLY GREATER THAN
FDA USFDA ACTION LEVELS FOR POISONOUS AND DELETERIOUS SUBSTANCES IN FISH AND SHELLFISH FOR HUMAN FOOD